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The Economics of Research and Development

How Research and Development Capital Affects Production and Markets and Is Affected by Tax Incentives

Anwar Shah

A survey and synthesis of the theoretical and empirical literature on the economics of research and development.

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Summary findings

Certain themes and findings emerge from Shah's analysis of key relationships between research and development (R&D) and other factors. Among them,

R&D capital and the structure of production

- R&D capital facilitates the mapping of technological possibilities into economic opportunities.
- R&D takes time to accumulate and uses up scarce resources. The adjustment process from project initiation to product and process development typically takes three to five years.
- The marginal adjustment costs for R&D are higher than for plant and equipment.
- R&D capital is a complement to physical capital but is a substitute for labor in the long run.
- Output changes exert a much stronger influence on R&D capital than vice versa.

R&D capital and market structure

The value of cost-reducing R&D is determined by its profitability. Since private returns from R&D understate true social returns from such investments, R&D will be underprovided. And since R&D investments often represent large fixed costs, market structure in R&D intensive industries is going to be concentrated. This situation is, however, not unique to R&D. What is unique about R&D is the nature of spillovers. These spillovers reduce industry costs, but since they result in inappropriability of returns for the R&D performer, incentives to do R&D are reduced. Restoring appropriability does not help matters either because it results in industrial concentration, incorrect pricing of R&D, and higher social costs. Perfect appropriability may also result in excessive R&D because too many firms may be fishing for the same information.

The information asymmetry between an R&D performer and a financier distinguishes R&D investment from traditional risky investment. It is in the interest of the R&D performer to keep vital project information secret. But in the absence of detailed information, project financing may not be forthcoming. Asymmetric information also limits the R&D firm's ability to profit from its output.

Success breeds success. Since learning involves costs, successful firms possess an advantage over their rivals in enjoying greater possibilities for success. So, monopoly persists in the R&D capital market. Past successes from R&D investments lead to greater current R&D efforts by successful firms. These firms tend thereby to produce further innovations and thus widen the gap between themselves and their rivals.

Much R&D capital is concentrated in large firms, but it is more likely that they have become large because of their R&D successes than that they do more and more fruitful R&D because they are large.

Public policy and R&D investment

- Most industrial nations see the need to intervene through the tax code to encourage R&D activities. Empirical evidence on the effectiveness of such initiatives is limited.
- An analysis of parameter estimates for a cost function of the Canadian industries suggests that R&D tax credits had a significant positive impact on R&D investment in Canada. For every dollar of revenue foregone for the national treasury, $1.80 worth of additional R&D investment was undertaken. This suggests that properly designed tax incentives can further public policy objectives cost-effectively.

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RESEARCH AND DEVELOPMENT INVESTMENT, INDUSTRIAL STRUCTURE, ECONOMIC PERFORMANCE AND TAX POLICIES

by Anwar Shah

EXECUTIVE SUMMARY

This paper provides a selective survey and synthesis of the theoretical and empirical literature on the economics of research and development.

In the following, main themes emerging from an analysis of R&D and production structure, R&D and product market structure, rationale for public intervention for R&D investment and the effectiveness of tax policies for R&D investment are presented.

R&D Capital and the Structure of Production

R&D capital, as an input, includes scientific and engineering personnel, laboratories and equipment and related inputs. R&D capital serves as an input in a joint production of multiple outputs which include product and process development. R&D capital facilitates the mapping of technological possibilities into economic opportunities.

R&D takes time to accumulate and uses up scarce resources. It may take several years for a project to proceed from proposal to development stage. R&D capital accumulation serves to create new knowledge relating to new production techniques. Thus it ensures that the process of technical change is evolutionary and cumulative in character. Technological changer widens production opportunities for the economy by enabling it to obtain greater outputs with given inputs or the substitution of relatively cheaper inputs for relatively more expensive ones.

A special feature of R&D capital is the imperfect appropriability of returns as a result of intra- as well as inter-industry capital spillovers. Spillovers diffuse knowledge by channels such as patents,

cross-licensing agreements, R&D personnel mobility and inputs purchases. The overall impact of R&D capital spillovers on the incentives to undertake additional R&D investment is unclear in view of two opposing influences. First, the imperfect appropriability of returns from own R&D has a disincentive effect. Second, the desire to tap into the external knowledge an associated benefits promotes incentives to undertake own R&D to develop an internal capability to benefit from externally generated knowledge. The net impact of the above varies by industry and explains the paradox posed by some R&D intensive industries such as electronics and chemicals where the high levels of spillovers do not seem to have any detrimental effects on the incentives to undertake additional R&D investment.

The following broad conclusions emerge from a survey of the available empirical evidence relating R&D capital and the Structure of production.

- The overall adjustment process from R&D project initiation to product and process development takes three to five years.
- The marginal adjustment costs for R&D are higher than those for plant and equipment.
- The own price elasticity of demand for R&D capital is less than unity regardless of the time period considered.
- R&D capital is a complement to physical capital but a substitute for labor in the long run.
- The long run output elasticity of demand for R&D capital is close to unity. Short run elasticities are much smaller than those for the long run.
- U.S. subsidiaries in Canada and Canadian-controlled private corporations show similar response in the long run but the short run impact of output changes on R&D capital is more pronounced for the latter.
- Output changes exert a much stronger influence on R&D capital than vice versa.
- The contribution of R&D capital to the productivity growth is inconclusive but more recent work confirms U.S. findings of a positive and significant relationship.

- R&D capital spillovers are large and significant and as a result the social rate of returns on R&D projects exceeds the private returns by at least two-thirds of the private return in Canada.

R&D Capital and Product Market Structure

The value of cost reducing R&D is determined by its profitability. Since private returns from R&D understate true social returns from such investments, R&D will be underprovided. Furthermore, since R&D investments often represent large fixed costs, market structure in R&D intensive industries is going to be concentrated. The above situation is, however, not unique to R&D. What is unique about the R&D is the nature of spillovers. These spillovers reduce industry costs but since they result in inappropriability of returns for the R&D performer, incentives to do R&D are reduced. Restoring appropriability does not help matters either because it results in industrial concentration, incorrect pricing of R&D and resulting social costs. Perfect appropriability may also result in excessive R&D because too many firms may be fishing for the same information.

The information asymmetry between a R&D performer and a financier distinguishes R&D investment from traditional risky investment. It is in the interest of the R& D performer to keep vital project information secret but in the absence of detailed information, project financing may not be forthcoming. Asymmetric information also limits the R&D firm's ability to profit from its output.

The following broad conclusions emerge from a survey of empirical evidence on the relationship between R&D capital and market structure.

- Success breeds success. Since learning involves costs, successful firms possess and advantage over their rivals in enjoying greater possibilities for further success. Thus monopoly persists in the R&D capital market. Past successes of R&D investments lead to greater current R&D effort son the part of the successful firms. These firms, thereby, tend to produce further innovations and thus widen the gap between themselves and their rivals.

- The relationship between R&D and firm size is much looser and obscure than is implied by the usual statements of Schumpeterian hypothesis. While much of the R&D capital is concentrated in large firms, it is more likely that they have become large because of their R&D successes rather than that they do more and more fruitful R&D because they are large.
- R&D capital and industrial concentration are positively correlated upto moderate levels of industrial concentration.
- Intra-industry spillovers drive a wedge between the social and the private return in an industry as well as between the social rates across industries. Social rates of return diverge from the private rates by 50 to 150 percent depending upon the R&D intensiveness of the industry.
- In the presence of spillovers, the society's demand for R&D capital at the existing market rates of return significantly exceeds the private demand.

Public Policy and R&D Investment

It has been argued that social rate of return from R&D is higher than the private rate of return due either to the presence of spillovers or information asymmetries. Due to the presence of spillover, the R&D performer is not able to fully appropriate benefits associated with his activity. the presence of asymmetric information between R&D performer and financier limits financing of R&D projects. Project success warrants secrecy but project financing requires release of vital information. As a result many projects lapse, lacking financing. The asymmetric information in the R&D output market also limits the R&D firm's ability to achieve licensing gains from trade.

Most industrial nations see the need to intervene through the tax code to encourage R&D activities. Empirical evidence on the effectiveness of such initiatives is quite limited. This study examined the impact of Canadian R&D tax credits on R&D investment using a production structure

framework. The framework enables a researcher to trace the impact of tax policies and production and investment decisions of an industry. An implementation of this framework was carried out by using detailed data on inputs and outputs and factor and output prices and tax regime for 18 Canadian industries for the period 1963 to 1983. Provisions in the tax code were used to develop estimates for the user cost of capital. A system of simultaneous equations incorporating the cost function and derived input demand functions was estimated using non-linear interactive methods in translog form. The estimated cost function fitted the data well and also was "well-behave". An analysis of parameter estimates for this cost function suggests that R&D tax credit had a significant positive impact on R&D investment in Canada and for every dollar of revenue foregone for the national treasury $1.80 worth of additional R&D investment was undertaken. This suggests that properly designed tax incentive can further public policy objectives in a cost-effective manner.

INTRODUCTION

This paper provides a selective survey and synthesis of the theoretical and empirical literature on the economics of research and development. This paper is organized into various sections as follows.

Section 1 provides an overview of the theoretical underpinnings of the relationship between R&D capital and the structure of production and summarizes empirical evidence on the hypothesis presented in the theoretical literature. It highlights the special nature of the R&D capital as a factor of production. The nature of lags in R&D capital accumulation, adjustment process, relationship of R&D capital with other factors of production, rate of technological progress and output are surveyed. It further discusses the nature of R&D capital spillovers, the channels for their transmission, their impact on incentives to undertake R&D and possible mechanisms to internalize these externalities.

Section 2 deals with contemporaneous relationship between R&D capital and product market structure. The focus is on the following types of issues. What is the relationship between R&D capital, firm size, stock market value of the firm, product demand and the nature of competition? What are the effects of R&D spillovers on the industry performance? What is the impact of asymmetric information on R&D project financing as well as on the R&D firm's ability to profit from its output?

Section 3 outlines the case for government intervention in the R&D capital market, provides critical comments, indicates instruments of government support for R&D investment and briefs on the Government of Canada current initiatives for technology development. It also provides an overview of tax incentives for R&D in major industrial societies. The impact of tax policy on the cost of R&D capital is reviewed in the next section. The following section provides a survey of the broad empirical approaches to evaluate the effectiveness of government tax incentives for R&D investment. The rationale and limitations of each approach are presented. The section concludes with a description of the overall research strategy adopted in the present study.

Section 4 outlines the empirical approach and discusses the econometric results and draws some conclusions regarding the effectiveness of tax measures in promoting R&D investment in Canada.

The final section (Section 5) provides a summary of the entire study.

Three appendices to the study are provided. Appendix A provides a description and lists sources of data used in this study. Several procedures used in constructing various serious are also documented. Two additional appendices provide details of the direct grant support for R&D investment in Canada and the definition of the R&D capital adopted in the Canadian Income Tax Act.

1. R&D CAPITAL AND THE STRUCTURE OF PRODUCTION: THEORY AND EVIDENCE

This section provides an overview of the theoretical underpinnings and the empirical evidence on the relationship between R&D capital and the structure of production. It highlights the special nature of R&D capital as a factor of production. Formalizing the role of R&D capital in the production process raises a number of issues. These issues include: the lags in R&D capital accumulation; the effect of R&D capital on productivity growth, input proportions and output expansion; and the impact of R&D capital spillovers on incentives to undertake own R&D investment. These issues are discussed and the empirical evidence is summarized in the following subsections. The final section draws some overall conclusions from the discussion presented in this section on the role of R&D capital in the production structure.

R&D Capital Factor Substituion and Adjustment

R&D projects create new knowledge as a result of accumulated expenditures over time. The cumulative results of all R&D projects constitute our stock of knowledge or the stock of R&D capital.[1] Since R&D capital plays a fundamental role in promoting productivity growth and output expansion in any economy, it is important to have as accurate a measure of such a capital as possible. R&D expenditures are usually considered a convenient measure of R&D capital. Nominal R&D expenditures are, however, an imperfect guide because they incorporate the impact of price inflation and do not reveal true changes in R&D activity levels. Furthermore, R&D expenditures relate to current year projects but knowledge capital at any point in time is a result of the accumulated expenditures from past projects. An appropriate deflator must therefore be used to derive real R&D expenditures. Bernstein (1986c) faulted the gross national expenditure (GNE) implicit price index and the consumer price index (CPI) as deflators for R&D expenditures and stressed the need for developing a specific R&D deflator.[2] He argued that there was a time varying bias associated with deflating R&D expenditures by the GNE or the CPI deflators because these deflators reflected changes in output prices while R&D expenditures related to inputs in the production process.

R&D investment projects, if successful, result in new products and processes. But there may be several lags between the time initial investment is undertaken and when product and process development is accomplished. Research and development takes time and it may take several years for a project to proceed from proposal to development stage. Process innovations typically are introduced gradually and product innovations require time for advertising strategy to command consumer acceptance. In general for any industry there may be a large number of projects that came on stream at different time periods, currently are in varying stages of implementation and likely to be completed at a sequence of time periods. R&D capital represents an aggregation and accumulation of these projects. The overall adjustment process could take several years. The transformation of R&D expenditures into R&D capital is affected by the speed with which new ideas are translated into product and process development and at the rate this knowledge is acquired by rivals in the industry. Nelson (1982) argues that an R&D capital accumulation process is costly and time consuming. One learns about efficacious R&D projects through one's successes and failures. The successes and failures guide one's future search efforts. One round of technological advance lays the foundation for the next round. The process of technical advancement is cumulative but translation of results into processes and products is subject to lags.

The available empirical evidence suggests that the overall adjustment process from R&D project initiation to product and process development often takes several years. Nadiri (1980) and Nadiri and Bitros (1980) estimate the intervening period to be three to five years duration and Bernstein and Nadiri (1984) found it to be even longer and of four to eight years duration. Ravenscraft and Scherer (1982) estimated a mean lag of R&D on net pre-tax profits for U.S. businesses to range from four to six years.

Mohnen, Nadiri and Prucha (1986) obtained a mean lag in the adjustment of R&D of five years for the U.S., eight years in Japan and ten years in Germany.

The available empirical evidence supports the hypothesis that adjustment costs for R&D capital exceed those for physical capital. For the United States, Bernstein and Nadiri (1985) estimated that marginal adjustment costs for R&D exceed those for plant and equipment. They further observe that this difference was more pronounced in industries that exhibit higher propensities to spend on R&D. For Canada, Bernstein (1985a) estimated that the marginal adjustment costs for R&D were higher than those for plant and equipment. Griliches (1979) estimates that the short-term nature of commercial research and development (see Mansfield and others in Williams (1973, pp. 87-90) serves to make the development lag peak between three to five years and rapidly decline afterwards with most of the original R&D output becoming public knowledge in about ten years.

R&D Capital, Output Expansion and Productivity Growth

R&D capital combines with traditional inputs in production to facilitate output expansion by reducing the cost per unit of output. Changes in the level of R&D capital change factor intensities by allowing substitution out of relatively scarce factors. This serves to decrease cost of production. The demand for R&D capital as an input in the production process in influenced by relative factor prices and output quantities. A number of empirical studies have examined the influences of changes in the prices of conventional inputs on the demand for R&D capital. The results from a few selected studies are presented in the following paragraphs.

Most of the studies found that the demand for R&D capital was price inelastic i.e. a one percent increase in its own price led to less than one percent decrease in quantity demanded. Furthermore, the long run own price elasticity of demand for knowledge capital was found to be higher than the short run estimate. Nadiri (1980) developed estimates of rental rates for R&D capital for U.S. manufacturing industries. He observed that a one percent increase in this rental rate caused a 0.6 percent decline in the demand for R&D capital. Bernstein and Nadiri (1986a) estimated own price elasticity of demand for knowledge capital to be -0.45. Bernstein (1984a) estimated long run own price elasticity of demand for R&D capital to be -0.35. The short run elasticity was about one third of this estimate. Bernstein (1984a) examined the factor price effects for Canadian controlled private corporations as well as U.S. subsidiaries. He estimated long run own price elasticities of demand for R&D capital for the two subsamples as -0.28 and -0.42 respectively. The short run elasticities were nearly half of the above estimates. Mohnen, Nadiri and Prucha (1986) found the own price elasticity of R&D capital for the U.S. manufacturing industries to be -0.04, -0.06 and -0.15 in the short, intermediate and long runs respectively.[3]

The empirical evidence suggests that physical and R&D capital are complements in relation to each other but substitute for labor in the long run. The short run evidence is mixed. Rasmussen (1973) found that the demand for R&D capital was sensitive to changes in the prices of labor and physical capital. Schwartz (1983) studied the relationship between R&D capital and three other factors of production namely labor, physical capital and energy for fourteen manufacturing industries in Canada. His results suggest that exogenous changes in R&D capital lead to increased requirements for all three remaining factors of production studied. Bernstein and Nadiri (1984) found physical and R&D capital to be complements. The demand for R&D capital on average declined by 0.2 percent for one percentage point increase in the rental rate on physical capital. The labor and R&D capital on the other hand were substitutes. A one percentage point increase in the rental rate of R&D capital in the long run resulted in a decline of 0.25 percent in labor demand. Bernstein (1984a) found confirmation of the U.S. evidence on the complementarity between R&D and physical capital and substitutability between R&D capital and labor inputs. In the long run one percentage point decrease in the rental rate for R&D capital resulted in an increase of about 0.05 percent in the demand for physical capital but a decrease of about 0.40

percent in the demand for labor. In the short run, the same estimates were 0.01 and 0.25 respectively. This study showed that R&D and physical capital inputs were complementary to each other but substitutes for labor both in the short and the long run. Mohnen et al. (1986) estimated that labor and R&D capital were substitutes, whereas labor and capital were complements in Japan and in Germany but substitutes in the U.S. Capital and R&D capital were complements in the U.S. and in Japan and substitutes in Germany.

R&D Output and Output Expansion

Output expansion has been considered an important determinant of the demand for R&D capital in much of the empirical work. For example, Nadiri and Bitros (1980) for a sample of firms in five U.S. industries observed that, on the average, a one percent increase in output generated a 0.7 percent increase in R&D capital. This figure was smaller for the subsample of large firms only. Bernstein and Nadiri (1984) for four U.S. industries found the long run output elasticity of demand for R&D capital to be greater than unity. For Canada based on a sample of major R&D performing firms, Bernstein (1984a) found this elasticity to equal unity. The short run estimate for this measure was about one-quarter of that for the long run. Bernstein (1984b) concluded that the short run output elasticity was higher for Canadian-controlled private corporations than for U.S. subsidiaries in Canada but the long run elasticity was invariant to the control or ownership of the firms. Bernstein (1985a) estimated the output elasticities of demand for R&D capital to equal 1 and 0.2 in the long and the short runs respectively. Mohnen et al. (1986) for the U.S. manufacturing industries estimated short, intermediate and long run output elasticity of demand for R&D capital to be 0.16, 0.31 and 1.00 respectively. Thus we conclude that while in the short run the output expansion induces a less than proportionate increase in demand for R&D capital, in the long run, it leads to almost one to one increase in the demand for R&D capital.

R&D capital is generally shown to have a positive impact on output. Mansfield (1968), Minasian (1969) and Griliches (1973) estimated that on the average for U.S. manufacturing and other industries, a one percent increase in R&D capital led to a 0.1 percent increase in output. An early Canadian study on the subject by Globerman (1972) did not find any significant effect of R&D capital on output but a recent study by Switzer (1984) found results similar to the U.S. studies.

Quite a large number of studies have empirically investigated the relationship between R&D capital and productivity growth. Summary results of a few selected studies are presented in the following paragraphs.

R&D Capital and Total Factor Productivity Growth

Mansfield (1965, 1968) found that the rate of technological change is directly related to the growth rate of R&D capital. This result is invariant to the nature of technological change. For ten chemical and petroleum firms he found that 20 percent of the productivity growth could be attributed to growth in R&D capital when the technical change was disembodied. With a capital embodied technical change, the growth in R&D capital explains nearly 70 percent of the total factor productivity growth.

Griliches (1964) found that the R&D capital contributed to about 30% of total factor productivity growth in agriculture. In a subsequent study of U.S. manufacturing at two, three and four digit SIC level, R&D growth explained about 40% of the total factor productivity growth.

Terleckyj (1974, 1975, 1977, 1980) considered both the direct and indirect effects of R&D for twenty U.S. manufacturing industries. He defined direct effects as those arising from intraindustry R&D investment and indirect effects as those associated with interindustry transactions. His analysis credited privately financed R&D capital for 30% growth in total factor productivity. The indirect effects associated with privately financed R&D were found to account for nearly 78 percent of total productivity growth. The government financed R&D did not show any significant direct or indirect effects on productivity growth.

Griliches (1980a) related total factor productivity growth measures for 883 large U.S. companies during the 1957-1965 period to various measures of the growth in R&D capital and found a sizeable and significant positive effect of R&D on productivity growth. He obtained an elasticity of output with respect to R&D investments of about 0.07 and an implied average gross excess return of 27 percent (as of 1963), a significantly lower rate of return to federally financed R&D expenditures, and no clear evidence of scale effects either in R&D investment policies or the returns from it. The positive contribution of R&D to total factor productivity growth was also confirmed by Griliches (1980b).

Mansfield (1980) based on a sample of 20 U.S. manufacturing industries for 1948-66 and 16 U.S. petroleum and chemical firms during 1960-76 found that the growth rate of both the basic and applied privately financed R&D capital had a positive and significant influence on total factor productivity growth. For government financed R&D he found support for the Terleckyj results that it did not have any significant impact on productivity growth. He found a significant premium on basic research, on the order of 2 to 1 at the industry level and 16 to 1 at the firm level. Link (1981) also found similar results for 1973-78 based on data for 55 U.S. firms.

Nadiri and Schankerman (1981) decomposed total factor productivity growth into four components namely factor price effect, product demand effect, R&D effect and autonomous technical change effect. This decomposition was carried out for U.S. manufacturing at total, durable and non-durable levels of aggregation for four subperiods in the interval 1958 to 1978. They found that R&D and exogenous technical change ("the technology effect") dominated productivity growth in the earlier years and the factor price and product demand (the "scale effect") were the prime motivators for productivity growth in later years of the period studied.

Jaffe (1988), instead, suggests to decompose the Total Factor Productivity (TFP) growth into the following three factors: technological opportunities, market demand and R&D spillovers. Using data compiled at NBER relative to 573 firms during 1965-77, the author concludes all the three effects together have an impact on R&D demand. At the same time, in explaining TFP growth Jaffe (1988) cannot separate the effects of technological changes and demand. More robust is the result relative to R&D spillovers: in the innovation process, the R&D spillovers show a positive externality on neighbor firms' level of R&D investment and costs.

Scherer (1982) found that both the intraindustry and interindustry effects of R&D capital on productivity growth during 1945-65 were strong but appear to have weakened during the 1970s. He further found interindustry effects of R&D capital to be much stronger than the intraindustry effects.

Scherer (1983) concluded that 0.20 to 0.28 percent decline in productivity in 1978 could be attributed to lower level of R&D.

Levy and Terleckyj (1983) estimated a large impact of private sector R&D capital on private sector productivity, with elasticity of about 0.28. Comparable elasticity estimates for the government contract R&D was 0.065. No significant effect of all other government R&D on private sector productivity was found. These findings for government contract R&D were consistent with Levin (1980) and Scott (1984) indicating small but significant stimulative effects of government support for R&D.

Griliches and Mairesse (1984) for 100 large U.S. firms for the period 1966-77 found that the contribution of R&D capital to productivity growth was higher than that of physical capital.

Clark and Griliches (1984) found a statistically significant relationship between R&D intensity and the growth in total factor productivity, implying a gross excess rate of return to R&D of about 20 percent. This return is bigger for process R&D than for product R&D. These returns however, crucially depend on the presence of previous major technological changes in the respective industries, implying a major role for spillovers from the previous R&D efforts of other firms and industries.

Griliches and Lichtenberg (1984) for U.S. manufacturing industries at two and three digit SIC level found that the statistical relationship between productivity growth and R&D intensity grew stronger in the 1970s.

Lichtenberg (1984) found a negative and statistically significant relationship between government contract R&D and private sector productivity growth.

Baily and Chakrabarti (1985) on the basis of case studies of chemicals and textiles industries in the U.S. found a positive relation between innovation and productivity patterns. They attributed the slowdown in the U.S. manufacturing industries in the seventies partly to a slowdown in innovation.

Griliches (1986) used a sample of 911 large (1000 or more employees) U.S. manufacturing companies performing R&D during 1966-77 and reported three major findings: R&D contributed positively to productivity growth and seemed to have earned a relatively high rate of return; basic research appeared to be more important as a productivity determinant than other types of R&D; and privately financed R&D expenditures were more effective, at the firm level, than federally financed ones.[4]

Two earlier Canadian studies on the subject did not support U.S. findings. Lithwick did not find any significant relation between productivity growth and industry R&D expenditures. Globerman (1972) estimated a negative and statistically significant relationship between R&D capital and overall productivity growth.

A recent study by Switzer (1984) of fourteen industries attributed nearly 60 percent growth in factor productivity to the growth in R&D capital. Switzer further found that government financed R&D had no significant impact on productivity growth. Switzer results however, must be considered tentative as he did not test whether the value-added or total output (output inclusive of intermediate inputs) is the appropriate output measure. He also treated R&D capital and conventional factors of production asymmetrically. Profit maximization framework was used for the latter only.

An analysis of the impact of R&D on TFP growth in Japan is presented by Goto and Suzuki (1989). Moving away from the previous research, that used data based on financial statements, the authors construct and utilize data based on R&D expenditure. The empirical findings support the hypothesis that productivity growth of a firm is stimulated by other industries' R&D.

Robert Solow (1957) suggested that only 10% of the rise in US per capita output during the years 1909-1949 was due to growth in the capital/labor ratio. To explain the remainder of the increase, the more efficient use of inputs or the presence of technological changes needed to be considered.

Over the past few decades, many researchers have explored the determinants of the latter suggested two explanations. In particular, R&D investment is generally regarded as having a strong impact on total factor productivity (TFP) growth. Moreover, the links between technological change and productivity growth is been documented by numerous recent studies, which generally use R&D expenditures as an indicator of the intensity of technological change.

Englander and others (1988) test whether an increase of the R&D capital stock translates into an improvement in technology and productivity. Using industry-level data across countries for the years 1970 to 1983, the authors find that part of the TFP deceleration recorded in the 1970s may have been caused by a reduction of the generation of new technologies. In addition, they highlight the unequal distribution of innovation across sectors, which can be considered as one of the possible causes for the divergent trends in TFP growth and price inflation in manufacturing and service industries observed in many western economies.

While the strong positive correlation between R&D investment and TFP growth at the industry level is supported by several empirical studies, the results at the firm level have been much less robust. A significant improvement of the state of knowledge is due to Lichtenberg and Siegel (1991): using confidential Census longitudinal microdata, the two researchers find that a significant cause of the TFP growth during the years 1972-1985 is the R&D investment. Furthermore, it appears that investments in different types of R&D has a different impact on productivity growth: among all, only the investment in basic research strongly affects TFP growth. Another important finding is the strong positive correlation between the rate of growth of TFP and privately funded R&D. On the other hand, federally-funded R&D cannot be considered as a significant determinant of productivity growth.

The most important conclusion that derives from this body of studies is that the R&D spending is not responsible for the productivity slowdown of the 1970s, since it has been proved that both aggregate R&D intensity and the (estimated) impact of R&D on productivity growth experienced no decline during this period. On the other hand, since during the 1980's both the size and the efficacy of R&D investment has increased, we must take into account R&D investment to elucidate the rise in TFP growth in these past years.

As suggested in earlier paragraphs, capital accumulation is stimulated by technological changes, and it is responsible for the increase in output per hour worked. On the other side, Romer (1990) suggests that the technological change observed is more likely to be endogenous rather than exogenous, since it is primarily the consequence of rational actions taken by people in response to market incentives. This implies that market incentives have a central role in the process of translation of new knowledge into goods. Moreover, the good "new knowledge", an imperfect public good, has different features from other economic goods, since it comports only an initial fixed cost for its use.

The most important result that derives from Romer's study is that not only the level of income and welfare but also the rate of growth are affected by increases in the size of the market, i.e. "larger markets induce more research and faster growth" (Romer, 1990). In addition, the author suggests that the growth rate is an increasing function of the stock of human capital, but not of the total size of the labor force nor of the population. This result helps to explain why countries with a stock of human capital too low may not experience any growth.

R&D Capital and Labor Productivity

Most studies on the subject found a positive and significant effect of private R&D capital on labor productivity growth rate. Griliches (1980) attributed 30 percent of the growth in labor productivity of six U.S. industries to R&D capital accumulation. Nadiri (1980) placed the same figure at 35 percent for the aggregate U.S. private sector. Canadian results were somewhat mixed. Postner and Wesa (1983) and Hartwick and Ewan (1983) concluded that there was no significant relationship between growth rate of labor productivity and R&D capital accumulation in Canada. However, when Postner and Wesa (1983) considered inter-industry effects they found that the indirect effect of R&D investment on labor productivity was positive and significant. Longo (1984) estimated that the growth in R&D capital accounted for 16 to 60 percent of labor productivity growth in major R&D performing industries.

R&D Capital and Spillovers

A special feature of R&D activities is that a firm can augment its R&D capital stock by simply profiting from the R&D results of another firm. The knowledge that is acquired without there being a market transaction for it is commonly referred to as an R&D spillover. The presence of spillovers suggests that the spillover generating firm cannot completely appropriate the returns associated with its R&D capital. Thus R&D spillovers arise due to the inability of the R&D performers to exclude others from freely or at a lower cost obtaining the benefits of new R&D capital. In the presence of these spillovers the R&D investor may not be able to earn sufficient return on investment and thereby the incentive to undertake R&D is diminished.

Spillovers diffuse knowledge by a wide variety of channels. Foremost of these channels are patents, licensing agreements, R&D personnel mobility and input purchases. Patents enable firms to receive vital information which could be used to patent around the original invention. Royalty payments would not reflect the social value of a patented invention if the ideas of the patentee are being successfully exploited to their own ends by other firms. Cross-licensing agreements also serve to transmit spillovers. Licensing fees may not fully reflect the benefit recei·'ed from this knowledge transfer because the initial recipient may recover fully or partially his initial costs through cross licensing. The mobility of R&D personnel from one firm to another is potentially a very important source of spillovers. The formation of AMDAHL by a former IBM engineer illustrates the importance of this mechanism in knowledge transmission. Input purchases have also the potential of generating spillovers if the input prices do not fully reflect the R&D costs of the sellers. For example, the purchase price of computers in general do not reflect all the cost-reducing possibilities open to downstream or purchasing firms. The above discussion of spillover transmission covers only some better known formal mechanisms and omits important informal processes. For example, the U.S. National Aerospace Program and the Pentagon do not sell anything to hospital supplies industries but major advances in medical technology have been a spinoff of the R&D done by the former institutions.[5]

It was noted earlier that the existence of these spillovers leads to imperfect appropriability of returns to R&D capital and acts as a disincentive to undertake own R&D investment (see also Arrow 1962). Reinganum (1981) and Spence (1984) have formally showed that as R&D spillovers in a given industry increase, the incentives to undertake R&D diminish. Thus the larger the spillover the lower will be incentives to undertake R&D investments. Spillovers also affect productivity by diffusing the knowledge relating to less costly production processes. More recently Cohen and Levinthal (1985) have argued that the above discussion assumes that the technical knowledge which "spilled over" is a public good like a radio signal or smoke pollution in that its effects are costlessly realized by all affected agents. They argue that the above was not true of industrial R&D because the assimilation or absorption of this knowledge by other firms, on the other hand, is not well recognized.[6] This process depends on a firm's capacity relating to the assimilation or absorption of externally generated knowledge. Nowery (1983a, 1983b) state that a firm must invest in its own R&D to be able to utilize information which is available externally. He observed that the more sophisticated is externally generated knowledge, the greater is the need for complementary in-house research to exploit it.

Cohen and Levinthal (1985) present a formal model to demonstrate that the overall impact of R&D capital spillovers is ambiguous due to two offsetting effects. A negative effect associated with imperfect appropriability of returns from own R&D investments and a positive incentive effect in order to assimilate the scientific and technological findings generated by firms, universities and public agencies.[7] Following Cohen and Levinthal approach, Bernstein and Nadiri (1989) examine three effects associated with the intra-industry R&D spillover: first, costs decline for the externality-receiving firms as a consequence of knowledge's increases; second, factor demands changes in response to spillovers have an impact on production structures; third, R&D spillovers affect the rates of capital accumulation. As a consequence, the combined effect of these three factors decreases the rate of R&D investment and it is R&D capital-reducing. Nelson and Winter (1982) also suggest that since much of the detailed knowledge of organization routines is acquired only through experiences within the firm, the internal R&D capability to recognize the value of, to assimilate and to use externally generated knowledge in a timely fashion is essential for success in a competitive and technologically progressive environment. The existence of positive incentive effect helps resolve the paradox posed by the electronics and chemical industries where high levels of spillovers do not appear to impede the level of investment in research and development. Their results suggest that the high level of spillovers, combined with rapid scientific and technological advances from sources both inside and outside the industry, provide an incentive for the firm to maintain high levels of absorptive capacity which, in turn, elicit sufficiently high levels of R&D that more than offset the negative appropriability effect.

Empirical evidence on the R&D spillovers is scant and only a few studies have estimated their impacts with any rigor. Mansfield et al. (1977) calculated social and private returns using methods discussed above for seventeen innovations. They found that median social return was twice as large compared to the private return (56% vs. 25%). Further that the private rate of return in one third of the cases "was so low that no firm, with the advantage of hindsight, would have invested in the innovation, but the social rate of return from the innovation was so high that, from society's point of view, the investment was well worthwhile" (Mansfield et al. 1977, p. 235). Bernstein and Nadiri (1986a) also reach similar conclusions. Using U.S. data they found that the excess of social return over private return varied from a low of 9 percent for machinery to a high of 76 percent in petroleum products industries. The average was 40 percent for the sample as a whole.

A Canadian study on the subject by Bernstein (1985a, 1985b) employed a production structure methodology and data on seven industries for the period 1978 to 1981 to estimate the impact of R&D spillovers. It concluded that the social rate of return on R&D projects greatly exceeds the private rate of return. In industries with a high propensity to spend on R&D, the net of depreciation real social rate of return was 25 percent in 1981, or more than double the net real private rate of 11.5 percent. In industries with low R&D spending propensities, the social rate of return was 20 percent or more than two-thirds greater than the private rate. He attributed the high rates of social returns to spillovers associated with R&D investment. He found the society's overall demand for R&D projects to be 75 percent greater than the actual demand observed for 1981. These results are consistent with Longo (1984) who found high rates of return to R&D capital. Bernstein attributed the high rates of return found by Longo to be due to spillovers.

More recently, Bernstein and Nadiri (1989)[8] estimate "the cost-reducing, factor-biasing and capital adjustment effects of the spillover", described in the previous page, for four industries (chemicals, petroleum, machinery, instruments) between 1965 and 1978. The existence of R&D spillovers implies that the social and private rates of return to R&D capital differ: even in this case, as in the one examined by Bernstein (1985a, 1985b), the social return exceeds the private return in each of the four industries analyzed.

A later canadian study focusing on the subject supports the U.S. findings. Using data for nine major Canadian industries, Bernstein (1989)[9] estimates the effects of inter-industry R&D spillovers on production costs: all nine industries are influenced by R&D spillovers and, in particular, six of them are affected by multiple spillover sources. The author computes also the rate of return to R&D capital for each industry and finds that it is generally two and an half to about four times greater than the private rate of return on physical capital. Furthermore, as for the U.S. industries, the private rate of return generated by R&D capital is between three or four times smaller than the rate of return inclusive of the inter-industry spillover effects.

United States and other western countries since 1960s have experience a decline in the ratio of both the number of registered inventions to real R&D expenditures and to the number of scientists and engineers (S&E) engaged in R&D. The magnitude of the decline by 1990 is impressively large: for United States, United Kingdom, Germany and France the patent/S&E ratio were only 55, 44, 42, and 40 percent of their 1969-70 levels. Some explanations advanced are as follows.

Griliches (1989, 1990) considers the rising costs of dealing with the patent system as the main reason. As a consequence, researchers have patented fewer of their inventions. From this prospective, the decline of the patent-R&D ratio can be viewed as the result of "a decline in the propensity to patent inventions, rather that a decline in the actual number of inventions" (Griliches, 1990).

Evenson (1984, 1991, 1993), instead, has argued that the productivity of the research sector has decreased because of the depletion of technological opportunities. Using a search-research model of invention potential, Evenson tests whether there are common economy-wide effects on changes in the patent/R&D and patent/S&E ratios and whether there are common industry effects. The results (Evenson 1993), based on a four countries- seven industries data set, provide strong support for the "demand-side explanation" and particularly for the importance of the foreign demand. In the pooled-industries specification, growing domestic demand and growing foreign demand are associated with lower patent/S&E ratios.

Kortum (1993) emphasizes that Evenson's demand-side story is not capable of explaining a relevant fraction of the decline in the patent-R&D ratio. From his point of view, the value of patents has been raised by the expansion of the markets and that competition in the research sector has implied a greater R&D expenditure per patent. In particular, his equilibrium model of industry growth predicts that an industry converges to a steady state in which the invention/R&D ratio continually falls if there is sufficient growth in demand. But this result is not robust: data from 20 U.S. manufacturing industries show a growth in demand not rapid enough to explain the decline in patent/R&D ratio. On the other hand, the data corroborate his intuition that the expansion of markets translates into increasing value of an invention and higher research expenditures per invention.

Part of the empirical evidence relative to R&D is been already described in the previous sections. The objective of the next paragraphs is to highlight few studies which estimate R&D, their features and their impact on the economic system.

The R&D costs during 1970-1982 for 12 U.S.-owned pharmaceutical firms were estimated by DiMasi and others (1991): the cost estimates were substantially higher than in previous studies because of the inadequate measure of R&D costs (Hansen 1979). In particular, the average cost of New Chemical Entities (NCE) development was estimated to be 231 million dollars[10], 2.3 times in real terms higher than previous estimates.

Data from 191 US manufacturing firms are used to analyze the direction of causality, in a Granger sense, between R&D and investment for the period 1973-81 (Lach and Schankerman, 1989). Two interesting findings of this study are: the relationship between R&D and investment is unidirectional, in the sense that "R&D Granger-causes investment" but not vice versa. Second, the firm's investment program and R&D program are affected in the long run by some "common factors". Moreover, the response to a change of these common factors is persistent over time.

The relation between trade flows and R&D is described in a study by Charos and Simos (1988). Using a multi-input, multi-output model the authors estimate the import demand and export supply functions for United States. The results of the study highlight the positive relation between R&D and level of imports; moreover, exports are found to be human capital intensive while investment goods are R&D intensive.

2. R&D CAPITAL AND PRODUCT MARKET STRUCTURE: THEORY AND EVIDENCE

This section provides a survey of the theory and evidence relating contemporaneous relationship between R&D capital and product market structure. The focus is on the following types of issues: What is the relationship between R&D capital, firm size and the nature of competition? What are the effects of R&D spillovers on the industry performance? What is the impact of asymmetric information on R&D project financing as well as on the R&D firm's ability to profit from its output? The final section provides some tentative conclusions relating the issues discussed in this section.

R&D Capital and Technological Competition

It has long been recognized that technological innovations effect market structure and since Schumpeter's (1950) important work that market structure also influences both the level of spending and the appropriability of the R&D. In his "Capitalism, Socialism and Democracy," Schumpeter (1950) argued that a market structure involving large firms with a considerable degree of market power is the price that society must pay for rapid technological advance. the Schumpeterian hypothesis has been contested in the recent literature. For example, Kamien and Schwartz (1975) and Scherer (1980) pointed out that it was unclear whether highly concentrated markets enhanced the appropriability of R&D investment or whether the opposite was true (Fellner 1951, Arrow 1962). Levin and Reiss (1984) investigated the relationship between market structure and R&D investment using a detailed industry equilibrium model where concentration, R&D intensity of output and advertising intensity were all jointly determined. They found a strong positive effect of R&D on industry concentration and a negative effect of concentration on R&D intensity which became positive for industries with a high share of product rather than process R&D.

Nelson and Winter (1982) also postulated a model of Schumpeterian competition and focussed on the competitive contest among innovators and imitators. They observed that not only a relatively concentrated industry would have a tendency to provide higher level of R&D but it would also be true that production and technical advance would be more efficient in that setting. They stated that where innovative R&D is profitable, the firms that spend on innovative R&D (and hence have a higher ratio of R&D expenditures to output) tend to grow faster than the imitators but in such a competition small firms are eliminated. On the other hand where innovative R&D is not profitable, but where market structure permits it to survive, the R&D intensive firms tend to be small.[11]

Dasgupta (1982) has questioned the causal interpretation given to the relationship between R&D investment and the structure of industries. He reasoned that innovative activity and industrial structure are simultaneously determined by technological opportunities, product demand conditions, and the structure of financial capital markets.

Technical advancement may create a "success breeds success" spiral. Merton (1973) termed it as the Mathew effect in reference to the passage in the Gospel According to Saint Mathew describing how the rich will get richer and the poor poorer. A number of empirical studies have investigated the "success breeds success" hypothesis and concluded that past successes of R&D investment lead to greater current R&D efforts. The successful firms tend to produce further innovations and widen the gaps between themselves and their rivals. Conclusions of a few selected studies follow. Phillips (1966) could not find support for this hypothesis based on data for eleven U.S. industry groups. A subsequent study (Phillips 1971) of the commercial aircraft market in the U.S. during 1932-65, however, provided some support for the above hypothesis. The latter study concluded that the stream of innovations resulted in a decrease in the number of manufacturers with large shifts in market shares. Comanor (1964, 1967) found that R&D was a major element of interfirm rivalry in the pharmaceutical industry, with profits largely dependent on firms' continued innovative success. Pavit and Wald (1971) concluded that opportunities for small firms diminish as technological competition becomes more intense. Grabowski (1968) for chemical, drug and petroleum industries found that past R&D success led to greater current R&D effort and resulted in widening the gap between technologically successful firms and their rivals.

Several studies have investigated the relationship between R&D capital and industrial concentration. Horowitz (1962) and Hamberg (1966) found a weak positive correlation with R&D expenditure per sales dollar and industrial concentration. Freeman (1965) found R&D to be an entry barrier in the oligopolistic international electronic capital goods industry. Mellor and Tilton (1969) observed that in the stage of technological competition, R&D costs act as a barrier to entry for semiconductors and photocopying industries. The stage of technological competition is characterized as one with many firms in the industry; the basic science well understood; and the research, relatively sophisticated and specialized. Scherer (1967b) and Kelly (1970) suggested that industrial concentration and R&D were positively correlated up to "moderate" levels of concentration. Comanor (1967) suggested that concentration was also associated with R&D capital in industries where technological and innovative opportunities are weak. Phillips (1971) for Belgian industry concluded that concentration and R&D effort tend to be positively associated in those industries with greatest technological opportunities i.e. R&D intensive industries. For Canada Globerman(1973) found that for R&D intensive industries, research intensity varied inversely with concentration (and directly with both foreign ownership and government financing). For other industries, no significant relationship between research and concentration was discovered. Rosenberg (1976) found that the percent of R&D employees in a firm increased with industry concentration. He also discovered that concentrated industries with firms of equal size (market share) were more R&D intensive. He further found that entry barriers, as measured by capital requirements, necessary advertising levels, and economies of scale, tended to have a positive effect on R&D intensity. Shrieves (1978) concluded that firms in concentrated industries tend to be more R&D intensive, as measured by R&D associated personnel, than firms in less concentrated ones. Leving and Reiss (1984) based on U.S. data for twenty manufacturing industries and three years (1963, 1967 and

1972) established a strong positive effect of R&D on industry concentration and a negative effect of concentration on R&D intensity which becomes positive for industries with a high share of product rather than process R&D. A recent study by Mansfield (1984) of twenty-four U.S. firms in chemical, petroleum, steel and drug industries covering sixty-five innovations introduced in the past fifty years indicated that less than half of the product innovations in all four industries seemed to increase the four-firm concentration ratio. He observed that the concentration increasing effects of R&D may be much weaker than is commonly perceived.

A large number of studies have addressed the relationship between R&D capital and firm size. Their overall conclusion is that larger firms do not engage in greater R&D activity relative to their size than smaller firms.[12] Furthermore, the technological possibilities between R&D inputs and innovative output do not display any economies of scale with respect to the size of the firm in which R&D is undertaken.[13] It is further indicated that industries facing greater technological opportunities tend to be more concentrated.[14] Some recent evidence is reported here. How and McFetridge (1976) studied the determinants of R&D spending by eighty-one Canadian firms in chemical, electrical, and machinery industries during 1967-71. They found that R&D spending increased more than proportionately than sales in the chemical and electrical industries only for intermediate size firms. Link (1978) found that size is not especially conducive to R&D in the electric utility industry beyond some modest level. Bound et al. (1984) concluded that the elasticity of R&D expenditures with respect to firm size (measured by sales and gross plant) is close to unity with some indication of slightly higher R&D intensities for both very small and very large firms in the sample.[15]

A number of empirical studies have confirmed that growth in demand for the products of an industry stimulates R&D activity within it. Shmookler (1966), Rosenberg (1976), Pakes and Schankerman (1984) and Mairesse and Siu (1984) support this result. Pakes and Schankerman (1984) however, established that very little of the observed differences in R&D intensity across firms can be explained by either past or even expected rates of growth of sales or by transitory fluctuations in these variables. At the industry level of aggregation however, they found that the variance in the growth rate does account for much of the variance in R&D intensity.

R&D Capital Spillovers and Industry Performance

The appropriability issue due to spillover effects has two prominent facets. One, it has positive effects on industry costs both in the R&D performing and related industries. Imperfect appropriability ensures that the results of R&D are disseminated elsewhere and result in decrease in costs. Since R&D involves major fixed costs and relatively minor variable costs, marginal cost of R&D would be small if not zero and allocative efficiency requires that it be priced so. For R&D receivers the relevant costs are the transmission costs of R&D and these are expected not to be significantly different from zero and hence R&D should be provided free. This problem is analogous to the provision of a public good and non-appropriability serves to price it correctly. Thus lack of appropriability has positive effects on R&D dissemination and industry costs. On the other hand the appropriability problem generates two opposing incentive effects for the R&D performer. A negative incentive effect works to discourage the firm from making large investments in R&D because it may not be able to fully appropriate the returns associated with such investments.[16] A positive incentive effect arises because of the complementarity of own R&D to spillover benefits. The net effect of these two opposing influences will determine whether the appropriability problem induces a lower or higher level of R&D investment undertaken by any firm. Thus the presence of imperfect appropriability may not necessarily lead to underinvestment in innovative activity.[17]

Levin and Reiss (1984) modelled spillover effects as the influences of firm's own R&D expenditures on costs of all other firms in the industry. They specified spillovers to be a function of share of R&D devoted to new or improved products and the ratio of government R&D to sales. They estimated that the share of R&D devoted to new and improved products had a positive impact on the inter-firm spillovers but that the government funding diminished spillovers. The latter result was unexpected but the authors argued may be plausible as the government support for R&D in the U.S. is mostly for large scale capital intensive defense systems which are not cheaply replicable for private sector applications.

Bernstein (1985b) using Canadian data found that the intra-and interindustry spillovers reduced average production costs of the spillovers receiving firms. The interindustry spillovers resulted in significant cost savings to Canada as a result of the R&D investment. He further established that spillovers from the high R&D propensity industries stimulated further R&D investment by the same industries. The low-propensity R&D industries on the other hand, substituted the knowledge from these spillovers for their own projects. His overall conclusion was that in industries that exhibit relatively rapid technological developments, Canadian firms need to carry out their own R&D projects to remain competitive.

Jaffe (1986) modelled R&D spillovers by examining whether the R&D of neighboring firms in technology spade had an observable impact on the firm's R&D success. Based on U.S. data he found that firms whose neighbors did much R&D produced more patents per dollar of their own R&D, with a positive interaction that gave the high R&D firms the largest benefit from spillovers. In terms of profit and market value, however, there were both positive and negative effects of nearby firms' R&D. The net effect was positive for high R&D intensive firms, but firms with R&D about one standard deviation below the mean were made worse off overall by the R&D of others.

R&D Capital and Information Asymmetry

It is frequently argued that returns from investment in R&D are more uncertain than from traditional investment. As a result, risk averse individuals discount these returns more heavily compared to investment in other forms of capital. This argument is plausible but may be of minor importance because the differentials in after tax returns from R&D are often greater than the returns from traditional investment by margins that could not be explained by risk premium alone. Furthermore most firms undertake a diversified portfolio of R&D projects and as a result although the risk associated with any particular project failing may be quite large yet for the group of projects in the portfolio as a whole there may be little risk of failure.

Simply because R&D is risky does not mean that it should be treated any differently than other risky investments e.g. oil exploration and development or futures markets. What is special about R&D is information asymmetry between R&D performer and financier. It is in the interest of R&D performer not to release vital information relating to the project to an outside party because of the fear that release of such information may jeopardize his chances of success or someone else may capitalize on that information. But to raise capital for a project requires releasing the information about the prospective returns from the project. In the absence of detailed information necessary financing for the project may not be forthcoming. The above mimics an adverse selection problem. Since information about the project is withheld from the financier, he could not determine whether or not the project would be a good risk. As a result an imperfect market for financing R&D projects emerges providing an inadequate level of financing. This problem arises in a variety of situations and is commonly referred to as the "agency paradigm". As an example suppose an inventor seeks to initiate a project and offers to sell shares in the project to obtain necessary financing. A potential investor would be uncertain as to the success of this project in the absence of adequate data on project feasibility and the commitment of the inventor. To inspire greater confidence in the project by outside investors, the investor must assume a substantial share of risk by buying a majority interest. This insures potential investors against any moral hazard associated with the project. This means, however, that the project may not be undertaken at all.

Shapiro (1985) has argued that asymmetric information limits a firm's ability to achieve the licensing gains from trade in R&D. Asymmetric information stands in the way of parties striking a deal. Further it may be difficult for the innovator to let others use his invention without giving them useful information in the on-going competition to acquire additional patents. It may also be costly or impossible for the licensor to monitor the licensee's output so as to charge per unit royalties.

Asymmetric information cannot only be considered as a constraint in the patent acquisition's process (Shapiro, 1985), but can also be viewed as an entry-barrier (Chen, 1991). In a model with incomplete information, in fact, a new firm faces an externality since the quality of its products is unknown to the customers. As a consequence, the firm cannot quantify the effects of its R&D investment on the average quality of production. The optimal way to internalize this externality is to implement R&D subsidies jointly with an entry fee. If firms can signal the quality of their products, then the previous policy becomes not socially optimal since it reduces the incentives for new firms to enter in the market.

The positive effect of R&D subsidies and their relation with market structure are also recognized by Nakao (1989). Using a model with Bertrand competition among firms, the author suggests that R&D subsidies would be the socially optimal policy only in the case of cooperative oligopoly. In the case of competitive oligopoly taxes would be the optimal instruments to internalize the externality present in the economy. Furthermore, the non- cooperative Bertrand behavior of the firms or the joint R&D ventures lead to a decline in the level of welfare of a society.

An interesting finding relative to the determinants of market structure is suggested by Belman and Heywood (1990). Testing the correlation between high worker quality and concentration of the market, the authors estimate that including R&D measures leads to a break-down of such relation: better quality workers are employed in industries with large R&D expenditures "which happen to be concentrated" (Belman and Heywood) because of the dynamism and the technological opportunities of such industries.

To analyze the dynamic effects of product innovation and R&D investment on market structure, researchers have often assumed that the R&D technology was stochastic. Using this approach, Aoki (1991) compares a deterministic R&D model with a stochastic one. The results suggest that the deterministic feature of R&D investment can help to explain the continual leadership of one firm in a particular industry. It follows in this setup that the only effect of stochastic R&D (jointly with the uncertainty of a successful outcome) is to increase the duration of the competition among rival firms.

Isaac and Reynolds (1988) employ a stochastic model of R&D investment to determine the effects of market structure and degree of appropriability on R&D spending. The simulations run by the authors suggest that both the size of the market and the degree of appropriability are negatively correlated with the level of R&D spending per firm (but a rise in the size of the market will affect positively the aggregate R&D spending).

The costs and the benefits deriving from a new technology are key variables in the innovation process. Lane (1991), using an adjustment model, tries to isolate the factors that affect the investment decision for the coal mining sector in United States between 1945 and 1975. The main results suggest that there exists a positive relationship between high level of captive production and leaders in the innovation process. Moreover, the degree of vertical integration has a positive incentive on the adoption decision.

How investors evaluate the market value of a firm is the focus of the work done by Shevlin (1991). His starting point is the consideration whether assets and liabilities of a R&D firm are affected (positively) by a particular type of off-balance sheet financing, the R&D limited partnerships (LP). Empirical analysis using a sample of 103 R&D LPs and for 5 years suggests that the existence of LPs (usually reported in footnotes of the balance sheet) provides a significant information to capital market agents in the investment process.

On the same line of research, Chan et al.(1990) examine the impact of the announcements of changes in the level of R&D expenditures on stock prices. Over the period 1979-85, United States stock markets responded to R&D changes' announcements with a long term perspective: the share value of a firm appears to be positively correlated with the rise in R&D, even if the earnings of few firms initially decline. However, this result doesn't hold for firms defined as "technologically mature" (as steel, oil refining or nonferrous metals), for which the announced change in R&D expenditure has a negative impact.

3. PUBLIC POLICY AND R & D INVESTMENT

Rationale for Public Intervention

The case for government intervention in R&D activities is well known: The social rate of return from R&D is higher than the private rate of return so that it left solely to private initiative and investment, there will be underallocation of resources to innovative activities. Several reasons have been cited for the disparity between social and private returns. These include:

Externalities

Due to the presence of spillovers, the R&D performer is not able to fully appropriate the benefits associated with his R&D activity. Due to the presence of large numbers either on the externality generating side or those affected by it, a privately negotiated settlement is almost never reached. The situation can only be alleviated by governmental action. The same argument for public intervention is sometimes couched in terms of public good nature of R&D capital. Once knowledge has been created, it is almost freely appropriable. Hence strong incentives for free ridership are created.

This line of reasoning has not escaped criticism. For example, Dasgupta and Stiglitz (1980) showed that in the presence of patents, firms would undertake socially excessive R&D expenditures in their attempts to deter entry with patented innovation. Their analysis, however, ignores both the positive and negative incentives effects of R&D spillovers. Hirscheifer (1971) has also argued that R&D expenditures in general would be undertaken beyond their optimal levels because too many firms would be "fishing" for the same piece of information. Spence (1984) also argued against restoring appropriability. He stated that restoring appropriability not only may create monopoly or monopoly power but also it incorrectly prices the good that R&D has created. An alternative effect of near perfect appropriability, he argued, would be the creation of redundant and hence excessive levels of R&D at the industry level. Thus, there is a tradeoff between positive incentives of appropriability on the one hand "and the efficiency with which the industry achieves the levels of cost reduction it actually does achieve, on the other," (p. 102). Spillovers, therefore, have a positive partial effect on industry's costs and a negative effect on incentives. On the whole, Spence argued that potential industry performance is significantly better with high spillovers (or low appropriability) because the output R&D is essentially a public good and if it is implicitly priced as a private good, the performance of the system will be adversely affected. Cohen and Levinthal (1985) also discount the negative incentives effect of spillovers. They argued that other firms' spillovers provide a firm with greater incentive to conduct own R&D, because only through its own R&D, a firm can tap into the knowledge and associated benefits generated by other firms.

The validity of this argument is considerably weakened by patents and the requirement for internal R&D capability to benefit from external R&D knowledge. The existing patent systems confer property rights for defined periods thereby restricting the use of new knowledge. Also the patent system ensures greater social benefits with wider use of knowledge after the expiry of the initial patent. The problem is that patents do not necessarily confer perfect appropriability because patents can be "invented around" or in some instances may not withstand a legal challenge or may simply be unenforceable as infringement might be difficult to establish. Levin (1986) however, notes that substantial resources need to be devoted to imitate an innovation even though it may not have any legal protection. Furthermore, a mere failure of the patent system to confer full appropriability does not necessarily represent a policy problem. In fact strengthening the patent system might result in almost complete capture of property rights. As a result too much effort might be devoted to inventions to capture any rents associated with future use of this invention. In any case, powerful incentives to innovate, even in the absence of a patent system, exist in many high technology industries e.g. the aircraft industry where multi-component systems provide built-in protection against imitation.

Information Asymmetries

It is frequently argued that returns from investment in R&D are more uncertain than from traditional investment. As a result, risk averse individuals discount these returns more heavily than may be warranted by proper calculation of riskiness of investment. Thus R&D investment is underprovided by the private sector.

The above argument is plausible but may be of minor importance because the differentials in after tax returns from R&D are often greater than the returns from traditional investment by margins that could not be explained by risk premium alone. Furthermore, most firms undertake a diversified portfolio of R&D projects and as a result although the risk associated with any particular project failing may be quite large yet for the group of projects in the portfolio as a whole, there may be little (average) risk of failure.

Perhaps the most powerful argument for public support of R&D is the presence of asymmetric information. The presence of asymmetric information between R&D performer and financier limits financing of R&D projects. Project success warrants secrecy but project financing requires release of vital information. As a result many projects lapse, lacking financing. The asymmetric information in the R&D output market also limits the R&D firm's ability to achieve the licensing gains from trade.

Tax Incentives for R&D in Major Industrial Societies

Government activities to stimulate R&D activities take a variety of forms. These include patent protection, government owned laboratories, government contracts for new products and processes, grants and loans, technical information services, support of education and training of scientists, engineers, and technicians and tax incentives. Of these activities, the focus is on the provisions in the tax code that are intended to stimulate R&D spending by private sector corporations.

The Government of Canada has a long history of using the tax code to encourage R&D investment. A few significant landmarks are reported below:

Brief History of Tax Incentives for R&D

Pre-1961 - Current expenditures on R&D were made fully deductible in the year incurred.

- One-third of the capital expenditures on R&D during the two preceding years were deductible in the current year.
- The Total deduction for R&D was limited to 5 percent of the previous year's taxable income unless the expenditures were approved by Revenue Canada.

1961 - Capital expenditures were made fully deductible in the year incurred or any year thereafter.

1962 - The requirement for approval by authorities of expenditures in excess of 5 percent of previous year's taxable income was eliminated.

- 50 percent of an increase in R&D expenditures (current or capital) over the base, defined as expenditures in 1961, was deductible from taxable income.

1967 - The 50 percent deduction for all R&D expenditures in excess of the 1961 base was replaced by grants under the Industrial Research and Development Incentives Act (IRDIA). This act provided a cash grant of 25 percent of capital expenditures and 25 percent of current expenditures in excess of the average expenditures made during the base period. The latter period was defined as the five years preceding the grant year. The 25 percent tax grant was non-taxable.

1975 - The deferral privilege for capital R&D expenditures was extended to current expenditures. Now both current and capital R&D expenditures could be written off in the year they were incurred or any year thereafter.

1976 - Industrial Research and Development Incentives Act repealed.

1977 - R&D investment tax credit introduced. The credits ranged from 5 to 10 percent, depending upon the region. The credit applied to all current and capital expenditures for R&D.

- The higher (10%) credit applied to R&D expenditures in the Atlantic provinces and the Gaspe are of Quebec.

1978 - R&D investment tax credits were raised to 10 percent for most of Canada, 20 percent in Atlantic Canada and Gaspe region, and a 25 percent credit for small business was introduced.

- An additional tax allowance of 50 percent of total R&D expenditures in Excess of the average level over the previous three years was introduced.

1983 - The rates of credit for scientific research expenditures were increased by 10 percentage points. The basic rate was raised to 20 percent of the R&D expenditures, except for expenditures made in the Atlantic provinces and the Gaspe where it was 30 percent. Small business credit rate was increased to 35 percent.

- The limit on the amount of tax credit a taxable firm can claim in a year was removed.
- Unused credits were permitted to be carried forward for seven years and carried back three years to offset federal taxes. 40 percent of unused credits earned in the year by the small business and 20 percent for large corporations could be refunded. This refundability provision was set to expire in May 1986.
- The 50 percent additional allowance was eliminated.
- As a temporary measure, tax credits not claimed by corporations were allowed to be transferred to individuals who purchased new issues of the corporation's stock.
- As a temporary measure, a portion of the value os unused credits was paid in cash to non-taxable corporations and unincorporated businesses.
- A new financing mechanism termed as Scientific Research Tax Credit (SRTC) was unveiled in April 1983 and made law in January 1984. Its principal elements were as follows:

- Investors earned the 50 percent tax credit by purchasing shares, or debt, or an interest in the products or revenues of the R&D performing company (whether related to R&D performing company or not).
- For every dollar raised by the R&D corporation under such tax credit financing, the corporation was liable for a refundable tax equal to the credits given by the investors.
- The R&D performing company, at any time after raising capital was permitted to renounce its claim to R&D tax deductions and tax credits it could otherwise claim. The R&D performing corporation was able to claim a rebate of its refundable tax credit at the rate of 50 percent of the amount of R&D expenditures for which it renounced its claim to tax incentives.
- Where the investor was an individual, the credit was set at 34 percent of the amount designated in respect of the qualifying investment made, to be offset against federal basic taxes. The computation of provincial income taxes meant that a total effective rate of credit of approximately 50 percent was provided. In the case of a corporate investor, the credit was 50 percent, to be applied against federal taxes.

1984 - Moratorium on certain "quick flip" SRTC investments was announced on October 10, 1984. Nearly 60% of SRTC claimed involved "quick flip" transactions, in which investors and the companies bought and sold the credits.

In a typical "quick flip" transaction" an investor would lend a research company $100 with $55 to be repaid on demand. The investor would then receive $50 from the federal government as a credit. After a short period, the investor would be repaid his loan. The repayment of $55 plus the receipt of $50 of the credit when the tax return was processed, provided the investor with a gain of $5.

1985 - SRTC repealed in May 1985.

- Tax credits earned by small Canadian-controlled private corporations for current expenditures on R&D were made 100 percent refundable. This provision was made effective May 23, 1985 with no expiry date.
- The provision that the expenditures eligible for the R&D incentives must be "wholly attributable" to R&D was replaced by a provision that an expenditure "all or substantially all" of which is attributable to R&D will qualify.
- The term "scientific research" was changed to "scientific research and experimental development". This change was done to recognize that the bulk of industrial R&D is concentrated on the experimental development of new products or processes rather than pure and applied research.

R&D Tax Credits currently available in Canada

Section 37 of the Income Tax Act allows taxpayers to deduct all current and capital expenditures for R&D in the year in which they were incurred. In addition an investment tax credit for R&D is also available to Canadian industry. The basic credit is 20 percent of the taxpayer's expenditure on R&D, except for expenditures made in the Atlantic provinces and the Gaspe where it is 30 percent. A 35 percent credit applies on the first $2 million of current expenditures on scientific research and experimental development by small business.

Credits may be used to fully offset federal taxes otherwise payable. Any balance of the tax credit in the year may be carried back for three years or carried forward for five years to offset federal taxes. A portion of any credit that is unused in the year it is earned is refundable to businesses. Large corporations are entitled to a 20 percent refund of unused credits in the year, while small corporations and unincorporated businesses are entitled to a 40 percent refund.

Tax Incentives for R&D in Major Industrial Societies

United States of America:[18] The U.S. Government has tried to lower the cost of private R&D through a combination of tax policy, direct spending and patent legislation. Major tax incentives include (1) allowing firms to deduct qualified R&D expenses in the year incurred. Section 174 of the Internal Revenue Code permits business taxpayers to deduct all research or experimental expenditures in the year they are incurred. Businesses have also the option to capitalize R&D expenditures and amortize them over a five year or longer period. Expenditures on capital assets such as land, building and equipment used for R&D are not eligible for immediate expensing. Since R&D expenditures are presumed to lead to an asset with a useful life in excess of one year, immediate expensing provides a tax incentive. (2) giving them a 25 percent credit on increases in qualified research and experimentation (R&E) expenses above the previous three years' average; and (3) permitting them to fund research through limited partnership. It is to be noted that the U.S. tax code makes a distinction between basic research and product development. While basic research costs are eligible for the credit and other tax benefits, only development costs incurred in the course of experimentation in the laboratory sense are eligible for special tax consideration. Other development costs must be capitalized.

The R&D tax credit passed by the Congress in 1981 has been criticized on the grounds that it provides only weak incentives for research and could potentially give incentives to defer such projects. For example, a firm steadily increasing its R&D spending will receive less credit per dollar of incremental R&D spending than the firm that raises its R&E spending for only one year. Perhaps, most important the credit does not help firms reverse a downward trend or even a one-year drop in R&E spending. Fifteen percent of firms fit in this category. The tax credit also is not of much use for new firms.

The R&D limited partnership (RDLP) reduces the cost of R&D to high technology firms by permitting tax shelters for R&D projects. An RDLP is typically sponsored by a corporation which may also serve as a general partner, seeking to fund research projects without incurring the disadvantages of more conventional financing. The limited partners who are usually persons in high tax brackets provide the funds; they can immediately deduct most of their investment from income and receive their return in the form of tax-advantaged long term capital gain. Like most such shelters, RDLPs use the tax laws to drive a wedge between what investors earn and what the issuing firms must pay; the wedge is revenue loss to the Treasury. If the research pays off, the revenue loss may be as high as 80 percent of the research costs.

Scientific organizations are also tax exempted as a measure of support for scientific research carried out by these institutions. In addition, individual and corporate contributions to such organizations are tax deductible up to certain limits.

The U.S. tax code also treats revenues from the sale of patents by individual investors as capital gains and thus qualifying for preferential tax treatment. Corporate transactions of patents and licenses also frequently qualify for capital gains treatment.

Since a disproportionate share of R&D investment is done by small business in the U.S., preferential tax treatment of small firms as opposed to large firms, indirectly provides incentives for R&D investment.

Finally, almost all incentives for investment also encourage R&D investment and affect the speed at which technical change is embodied in capital stock.

France: Government grants up to 50% of the cost of a project are provided for R&D investment. The grant is treated as a loan for tax purposes rather than as income to the company. Expenditures for R&D are fully deductible in the year incurred. R&D plant and equipment investment also qualifies for accelerated depreciation. Firms that do R&D exclusively receive special tax treatment. Royalties and patent sales are not taxed if reinvested within three years.

West Germany: All R&D expenditures can be deducted in the year incurred. Plant and equipment devoted to R&D is subject to accelerated depreciation allowances. A cash grant of 7.5% of R&D capital investment is available to qualifying R&D investment. Further cash or credit assistance is available to a number of R&D intensive industries. Individual and corporate donations for scientific purposes are tax deductible and corporate support of research organizations which execute a program of cooperative R&D for an industry receives a generous tax allowance.

Japan: All R&D expenditures and costs of developing patent rights can be either expenses immediately or amortized over several years. A 25 percent tax deduction is allowed on those R&D expenditures which represent an increase over the highest R&D expenditures which represent an increase over the highest R&D expenditures incurred by the company in any year since 1967. Special accelerated depreciation allowances are provided to approved investments in new technology. Joint research associations in certain industries can immediately expense the cost of new machinery and equipment or a new facility. Special tax incentives are provided to small and medium sized enterprises. A large number of government agencies provide direct support for approved scientific projects.

United Kingdom: R&D current and capital expenditures can be deducted in the year incurred. Corporate and individual donations for R&D do not qualify for tax deduction. Direct support for R&D investment is available from various government departments and agencies.

Tax Policy and the Cost of R&D Capital

The previous section noted that two types of tax incentives are currently available in Canada. First, the cost of R&D capital is reduced by allowing immediate expensing of R&D expenditures. This is equivalent to a 100 percent capital consumption allowance (CCA). Second, R&D current and capital expenditures are eligible for a tax credit which varies by size of business and location of activity. Thus both measures lower the cost of R&D and provide incentives to undertake more of such investment. To see the effects of these measures more clearly, consider a $1 expenditure on R&D. This expenditure would reduce the taxable income by $1 and assuming a marginal tax rate of 46 percent, the tax deduction will be 46 cents. The post-tax cost of a dollar of R&D expenditure is thus 54 cents. Contrast this to the case where R&D expenditures were eligible for a CCA rate of 30 percent and assume that future depreciation deductions are discounted at 15 percent. Under these assumptions, the present value of depreciation deductions is 67 cents. The tax reduction is obtained by multiplying this number by the tax rate and equals 31 cents. The post-tax cost of a dollar of R&D expenditure is then 69 cents, which is greater than the 54 cents under the immediate expensing provision.[19]

Next consider the combined effects of the deductibility provision and the tax credit on the cost of R&D capital. Suppose the credit rate is 10 percent. The deductibility provision in the absence of a tax credit reduces taxes by 46 cents per dollar ($1 x marginal tax rate) of R&D expenditure. The credit reduces the tax liability by 10 cents but reduces eligible R&D expenditures for deductibility purposes by the same amount. Thus the tax reduction from the deductibility provision in the presence of a 10 percent tax credit is 41 cents (.90 x .46) and the total tax reduction from both measures is 51 cents. The tax credit, therefore, contributes about 6 cents to tax reduction per dollar of R&D expenditure. The post-tax cost of a dollar of R&D capital under this scenario is 49 cents. Thus the subsidy rate is more than 50 cents per dollar of R&D expenditure. Table 4.1 reproduced from Bernstein (1986) presents estimates of post-tax cost of one dollar of R&D expenditures by size of business and by region of activity. Currently the post-tax cost of a dollar of R&D expenditure is lowest for large non-manufacturing industries in the Atlantic region (62% subsidy) and the highest for small firms anywhere in Canada (51% subsidy).

While the rate of subsidy is important, the effectiveness of subsidy also determined by the tax status of the firm. Incentives are much less attractive to firms in a non-taxable position. In 1980 such firms undertook 47 percent of total R&D capital expenditures (see Table 4.2).

Empirical approaches to evaluation of tax incentives have varied from opinion surveys to rigorously derived testable models and from partial equilibrium to general equilibrium analysis. This section provides an overview of the principal approaches, notes their key assumptions and caveats and surveys research findings of selected studies.

Survey of Firms

Opinion surveys of company executives have been frequently used to evaluate the effectiveness of R&D tax incentives. Mansfield and Switzer (1985) represents a recent example of such an approach using Canadian data. The findings of this study are presented below.

The authors divided Canadian R&D firms into two groups: (1) The 65 corporations doing most of the R&D in 1981; and (2) The remaining 1305 R&D performing firms. A stratified random sample of 55 firms was chosen and the company officials were interviewed to ascertain their views on the effectiveness of the two R&D tax credits in place during the early 1980s. An analysis of these responses suggests that the incentive effect of the two tax credits was much smaller than the revenue foregone as a result of these measures ($50 million of additional R&D at a cost to federal treasury of $130 million in 1982).

An objective assessment of the impact of tax measures is not possible through opinion surveys. Opinion surveys do not provide any data on observed behavior both before and after a policy change and hence the validity of their results is doubtful.

Estimation of Ad hoc/Eclectic Equations

This approach usually specifies R&D spending to be a function of a host of independent variables including R&D tax credit. Variables selection and model specification are most often based on a "fishing expedition" for a high coefficient of multiple determination, R^2.

Mansfield and Switzer (1985) specify an ad hoc model to estimate the impact of R&D tax credits on R&D spending by the Canadian industry. In their model, R&D spending by industry is a function of industry sales during the current year and a time trend. Parameters obtained in this equation were then related to the nature of prevailing tax incentives in each year. The results indicate that $132 million of federal tax expenditures for R&D produced $30 million of new R&D capital.

Investment Models

The following five principal models have been used to analyze tax incentives:

(i) The Flexible Capital Stock Adjustment Model or the Accelerator Theory of Investment;

(ii) The Q-Model;

(iii) General Forward-Looking Models;

(iv) Effective Tax Rate and Return-Over-Cost Models; and

(v) The Production Structure or the Adjustment Cost Approach.

A brief description of these approaches is given in the following paragraphs.

(i) *The Flexible Capital Stock Adjustment Approach*

The simple, or naive, form of the acceleration principle postulates a certain fixed relationship between the desired capital stock and output. It is argued that tax incentives affect investment through changes in desired capital stock by reducing the relative price of capital. For illustrative purposes the Hall-Horgenson approach is outlined here.

Employing a Cobb-Douglas production technology, the desired capital stock, K can be obtained as follows:

$$K_t^* = \alpha (P_t Q_t / c_t)$$

Where P = price of output

Q = quantity of output

c = user cost of capital

α = elasticity of output with respect to capital

Net investment (I_t) is a weighted average of past changes in the desired capital stock, such that:

$$I_t = \sum_{s=0}^{\infty} w_s K^{*}_{t-s}$$

By imposing restrictions on the sequence $\{w_s\}$, net investment becomes:

$$I_t = W_o \Delta K^{*}_t + W_1 \Delta K^{*}_{t-1} - W_2 I_{t-1}.$$

Recalling the equation for the desired capital stock, the investment function can be written as follows:

$$I_t = \alpha W_o \Delta \frac{P_t Q_t}{C_t} + \alpha W_1 \Delta \frac{P_{t-1} Q_{t-1}}{C_{t-1}} - W_2 I_{t-1} + e_t$$

where ϵ_t is the error term.

Changes in tax incentives alter the user cost of capital, which in turn changes the desired stock of capital. Changes in the desired stock of capital then lead to changes in net investment (or disinvestment).

Braithwaite (1975), May (1976) and Harman and Johnson (1978) used this general approach in evaluating Canadian tax incentives. Braithwaite and May focussed on the impact of the accelerated capital consumption allowances and reduced corporate tax rates for manufacturing and processing. Harman and Johnson looked at the CCAs and deferred allowances. Harman and Johnson employed the Coen Model, a variant of the Hall-Jorgenson model with better specification of the production technology and the speed of adjustment in response to changes in the user cost of capital. Harman and Johnson concluded that the incentives impact investment but the associated revenue loss is often greater than the investment gains.

(ii) *The Q-Theory Approach*

The essence of Tobin's "q" theory model is that a firm will invest as long as a dollar spent buying capital raises the market value of the firm by more than one dollar. Since q is defined as the ratio of the market value of existing capital to its replacement cost, then investment will take place as long as q is greater than unity.

Summers (1981) employed this general approach to examine the impact of various tax policies on investment. He assumes: (1) Constant returns to scale technology; and (2) Firms maintain a constant debt to capital stock ratio (b).

Firms maximize the market value of equity and bonds at time t:

$$V_t = \int_{t=0}^{\infty} \frac{(1-\theta)}{(1-c)} DIV_s \, \mu_s ds + B_t$$

where

θ	=	dividend tax rate
C	=	capital gains tax rate
DIV_s	=	after-tax profits minus investment expenses
		$[pF(K,L)-WL-pbik]\ (i-\tau)-(1-ITC-2-b)+(1-\tau)\phi pI+pbK(\pi-\delta)$
p	=	overall price level
i	=	nominal interest rate

τ = corporate tax rate

z = present value of depreciation allowances on a dollar of new investment

B = present value of depreciation allowances on existing capital

ϕ = adjustment cost function

I = investment

π = inflation rate

δ = rate of economic depreciation of the capital stock

$$\mu_s = \exp \int_t^s - \frac{(\rho+\pi)}{(1-c)}\, du$$

ρ = fixed real after tax return.

Firms choose an investment and financial policy to maximize the value of equity and bonds, subject to the constraint that capital accumulation equals net investment. Solving the optimization problem generates the following investment function:

$$I/K = h\left[\frac{\frac{(V-B)(1-C)}{pK(1-\theta)} - 1 + b + ITC + Z}{(1-\tau)}\right] = h(Q)$$

If an adjustment cost function of the following form is employed:

$$\phi = \frac{B/2\ (I/K - v)^2}{I/K}$$

then an investment function which is linear in Q results.

$$I/K = v + (1/B)Q$$

This is the basic equation estimated by Summers (1981).

(iii) *General Forward Looking Models*

The decision rule governing investment in the General Forward Looking Model (GFL) is identical to that in the q theory but the two theories differ in how the unobservable expectations are related to observable variables. Unobservable expectations have been defined in either two step, one step, or transformation procedures.

The two step procedure is based on a decomposition of the investment problem into expectation formation and given these expectations, the decision to acquire investment goods. Expectations are based on lagged variables and the parameters derived from expectations equations are used to forecast future variables that replace unobservable expectations. These variables are then used to estimate production and adjustment parameters.

(iv) *Effective Tax Rates and Return-Over-Cost Models*

Feldstein (1980) is the proponent of effective tax rate approach to incentives evaluation. Feldstein posits that net investment is dependent on the net-of-tax real return to capital. Net of tax real return depends on effective tax rate which is defined as the ratio of a comprehensive measure of all taxes assessed on capital income to operating income less depreciation.

The return-over-cost model (also presented by Feldstein) quantifies investment incentives by contrasting the maximum potential net return (MPNR) on a standard investment project with the cost of funds (COF). MPNR is influenced by tax incentives. Whenever the maximum potential net return exceeds the cost of funds, firms have an incentive to acquire more capital.

(v) *The Production Structure/Adjustment Cost Approach*

The essence of this approach is that capital is subject to adjustment costs in that investment causes output to be foregone, as factors of production are diverted to install the additions to the capital stock. As a result, firms cannot move instantaneously to a new level of the capital stock but instead must adjust over time to the desired level. For this reason, the capital input is termed a quasi-fixed factor, whereas the labor input (which adjusts instantaneously) is a variable factor.

To illustrate an application of this approach, a recent study by Jeff Bernstein (1985) is summarized here. Bernstein develops a dynamic model of corporate production, which integrates financial and production decisions. Output is a function of physical capital, R&D capital and labor, where both capital inputs are subject to adjustment costs. The production technology is represented by:

$$y(t) = F\{L(t), K_r(t), K_p(t), I_p(t), I_r(t)\}$$

$$F_j > 0 \; F_{jj} < 0 \; j = I_p, I_r$$

where p = physical capital

r = R&D capital

I = Investment

Firms operate in the interest of their shareholders and so maximize the present value of their equity. Equivalently the firms minimize costs subject to appropriate restraints. Inverting the production function yields the labor requirement function:

$$L = G(K_p, K_r, I_p, I_r, y)$$

The cost minimization problem then is:

$$\text{Min}_{I_r, I_p} \int_0^\infty e^{-\rho t} \left[W_L G(K_p, K_r, I_p, I_r, y) + W_p K_p + W_r K_r\right] dt$$

$$\text{s.t.} \quad \dot{K}_i = I_i - \delta_i K_i \quad i = p, r \qquad \left.\begin{array}{l} \\ \\ \end{array}\right] \begin{array}{c} \text{capital} \\ \text{Accumulation} \\ \text{conditions} \end{array}$$

$$K_i(0) = K_i^c > 0$$

where

ρ = cost of equity capital

$w_{L,p,r}$ = rental rates on labor, physical and R&D capital respectively

δ_i = depreciation rate of the ith capital stock.

If J (K_p, K_r, w_p, w_r, w_L, y) is defined to be the minimized present value of costs, then one can derive $\frac{\partial \rho_i}{w_p}$ and $\frac{\partial \rho_i}{w_r}$.

Solving these two equations generates a system of equations for L, K_p and K_r. Bernstein estimates this system of three equations. The nature of L, K_p and K_r depends on the particular functional form taken by J.

Bernstein considered the impact of two Canadian R&D tax incentives (the R&D investment tax credit and the special research allowance) on R&D investment. Note that this model could also be employed to analyze the effects of incentives on physical investment. Bernstein used a pooled set of cross-section and time series data for 27 firms for the period 1975-80. The incentives were evaluated in terms of increased R&D expenditure per dollar of lost revenue, for a realistic range of price elasticity of product demand. He found that one dollar increase in tax expenditures resulted in more than one dollar of new R&D capital.

Applied General Equilibrium Analysis

A large majority of complex interactions in an economy are assumed away by partial equilibrium analysis. An applied general equilibrium model on the other hand, can provide a disaggregated view of the economy and thereby yield quantitative estimates of all important interactions. It is therefore, a more valuable tool in assessing the relative merits of alternative tax policy changes.

Applied general equilibrium analysis entails several sequential steps. First, basic data are collected from a variety of sources. These data are then adjusted for microconsistency. Next the choice of model, functional forms and elasticity parameters are specified. Parameter values for model functions are then determined through calibration. A replication test is carried out to check that the calibrated parameter values are consistent with the original data on quantities and prices and the assumed model structure. Once this replication test is passed, a policy change is specified and a new (counterfactual) equilibrium is computed. Policy evaluation is then based on pairwise comparison between benchmark and new equilibrium.

The applied dynamic sequenced model developed by Hamilton, Mintz, Shah and Whalley (1985) estimates the impact of tax changes on investment, factor use, output, savings, public revenues and overall welfare gains and losses. This model could be applied to evaluate the impact of R&D tax incentives.

Directions For This Study

The above discussion suggests that a production structure approach yields important insights on the impact of tax policy on business production, investment and financing decisions. This study specifies a rigorous production structure framework and estimates it using flexible functional forms. The superiority of the empirical approach adopted in this study is demonstrated using theoretical criteria.

4. TAX POLICY, PRODUCTION STRUCTURE AND R&D CAPITAL

This study examines the production relationship in Canadian industries using a model which incorporates R&D capital as an input in addition to the usual factors of production namely physical capital, labor and intermediate inputs. The analysis of production relations traditionally have been carried out using a production function approach by specifying output as a function of inputs and by using functional forms which impose restrictions on factor substitution possibilities. Recent developments in production economics have resulted in improved representation of production technology by utilizing the dual relation between cost and production and by using flexible functional forms in econometric estimation.

Given a production function, there exists a corresponding cost function. This dual relation was formally established by Shepard's lemma (1953). The duality theory implies that if the firm minimizes costs and input prices are exogenous, and if the product transformation function, T(Q,X)=O, (where Q denotes output and X a vector of inputs), satisfies the usual regularity conditions (i.e. strictly convex isoquants), there exists a dual cost function C(Q,), where P is a price vector, which is as good a representation of the firm's production technology as the product transformation function and which satisfies the following regularity properties:

(1) C is non-negative, differentiable, non-decreasing, linearly homogenous and concave on P for fixed non-negative output Q.

(2) C is strictly positive for non-zero output Q and is strictly increasing in Q.

Thus for well behaved relationships, one can deduce the structure of production technology directly from the cost function.

Recent works of Diewert (1971) and others have demonstrated that the application of duality theorem and the specification of a flexible functional form eliminates the need for a priori restrictions on the production set. Furthermore, flexible functional forms allow us to test for separability (a firm's decision on the use of one or more inputs is independent of the rest of the inputs), homotheticity (relationship between scale and factor intensities) and consistency in aggregation. In view of these features, a flexible functional form approach is adopted here.

From the duality correspondence between the production and cost functions, one can utilize either of the two methods of deriving input demand and cost share equations.

(a) Postulate a functional form for the production function satisfying certain regularity conditions, and then solve for the output constrained cost minimization problem which is used in deriving the input demand function and hence the cost share equations.

(b) Postulate a differentiable functional form for the industry cost function satisfying certain regularity conditions and obtain the derived input demand functions by applying Shephard's lemma.

The cost function approach is more commonly used than a production function approach in estimating parameters because it has the following advantages:

(1) Estimation of parameters is much easier using a cost function than a production function.

(2) Tests on elasticities of substitution between factor inputs are more easily carried out with the cost function approach since the required standard errors are readily available.

(3) The production function method uses inputs as arguments while cost function has output and input prices as arguments. Thus a cost minimization approach implicitly assumes entrepreneurs make decisions on factor use according to exogenous prices, which makes the factor levels endogenous decision variables. Since the choice of inputs is endogenous to the firm and the production function approach is concerned with the direct use of inputs, this needs endogenous treatment of the input variables leading to a simultaneous

estimation problem. The cost function approach avoids this problem but requires that one assume that individual producers cannot influence prices.

(4) Given an exogenous shock on input prices, it would be easier to examine the impact on factor demands by using an estimated cost function than a production function.

(5) Recent productivity studies measure total factor productivity growth (TFP) as a sum of technical change effects and scale effects. However, in order to estimate TFP, or to separate scale effects from technological change effects an estimate of the scale elasticity is required. The scale elasticity can be obtained directly from an estimated cost function.

(6) Cost functions are homogenous in prices regardless of the properties of homogeneity in the production function.

(7) Prices are likely to be less collinear, then inputs. This implies that a cost function approach may encounter less multicollinearity than a production function approach.

Because of the above advantages, the cost function approach is implemented in this study. While the issue of choice among various flexible functional forms is far from settled, translog function is often shown to be preferable over alternative forms. The non-homothetic translog cost function will be used as the maintained hypothesis in this study.

The Model

In the specification of the translog function, a five input production model is considered here. The inputs are:

(1) Capital stock - structures (land and buildings) (S)

(2) Capital stock - machinery (M)

(3) R&D Capital stock (RDK)

(4) Intermediate inputs (II)

(5) Labor (L)

A translog cost function of the usual form incorporating these inputs can be represented as follows:

$$\ln C = \alpha_o + \alpha_Q \ln Q + 1/2\, \gamma_{QQ} \ln Q^2$$

$$+ \sum_{i=1}^{5} \alpha_i \ln P_i + 1/2 \sum_{i=1}^{5} \sum_{j=1}^{5} \gamma_{ij} \ln Pi \ln pj$$

$$+ \sum_{i=1}^{5} \gamma_{Qi} \ln Q \ln Pi$$

$$+ \phi_t\, t + 1/2\, \phi_{tt}\, t^2$$

$$+ \sum_{i=1}^{5} \phi_{tPi}\, t \ln Pi + \phi_{tQ}\, t \ln Q + e \qquad (1)$$

where C = total cost = $\sum_{I=1}^{5} P_i X_i$

P_i = price of input i

where i = S, M, RDK, II, L

X_i = quantity of input i

t = technological change

The translog cost function (1) is a second order logarithmic Taylor series expansion of a twice differentiable analytic cost function around unity.

Cost-minimizing derived demand equations for the various inputs are obtained from (1) by logarithmically differentiating this function with respect to input prices and applying Shephard's lemma i.e. $\frac{\partial C}{\partial P_i} = x_i$. The derived demand equations obtained from this process can be written as:

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{P_i X_i}{C} = S_i = \alpha_i + \sum_{j=1}^{5} \gamma_{ij} \ln P_j + \gamma_{Qi} \ln Q + \phi_{tPi}\, t \qquad (2)$$

where S_i is the share of the ith input in total cost. A "well-behaved" cost function must satisfy the following conditions:

(1) Hicks-Samuelson symmetry conditions

$$\gamma_{ij} = \gamma_{ji} \text{ (Slutsky symmetry)}$$

(2) Linear homogeneity condition (or zero homogeneity in prices) i.e., when all factor prices are doubled, the total cost will double. It can be shown that linear homogeneity implies the following restrictions:

$$\sum_{i=1}^{5} \alpha_i = 1,$$

$$\sum_{j=1}^{5} \gamma_{ij} = 0,$$

$$\sum_{i=1}^{5} \gamma_{ji} = 0,$$

$$\sum_{i=1}^{5} \gamma_{Qi} = 0,$$

$$\sum_{i=1}^{5} \phi_{tP_i} = 0, \qquad \text{for all } i,j$$

(3) Monotonicity: The function must be an increasing function of input prices i.e. $\frac{\partial \log C}{\partial \log P_i} \geq 0$, i = S, M, RDK, II, L

Due to the homogeneity constraint, only (n-1) share equations (2) are linearly independent and can be estimated simultaneously. Therefore, one of the five share equations is to be deleted leaving a system of five equations (the translog cost function and four share equations) to be estimated using either a non-linear multivariate system estimator or Zellner's seemingly unrelated regression technique (see Kmenta (1971), p. 518).

Elasticities of Substitution and Elasticities of Factor Demand:
Elasticities of Substitution (AES)

The elasticities of substitution (σ_{ij}'s) are specific to pairs of inputs (e.g. between inputs i and j) and as such summarize economic interrelations between two inputs only. In a two input specification, (σ_{ij}) must denote substitutability while in a more than two input case at least one of them may denote either substitutability or complementarity. Estimates of partial elasticities of substitution σ_{ij} can be obtained directly from the parameters of the cost function as follows:

$$\sigma_{ij} = \frac{\sum_{i=1}^{5} P_i X_i}{X_i X_j} \cdot \frac{\partial^2 C}{\partial P_i \partial P_j} = \frac{C}{X_i X_j} \cdot \frac{\partial^2 C}{\partial P_i \partial P_j}$$

The Hicks-Allen-Uzawa partial elasticity of substitution (AES) between inputs i and j can be written as:

$$\sigma_{ij} = C\, C \cdot C_{ij}/C_i \cdot C_j$$

where $C_i = \frac{\partial C}{\partial P_i}$

$C_j = \frac{\partial C}{\partial P_j}$

and $C_{ij} = \frac{\partial^2 C}{\partial P_i \partial P_j}$

For the translog cost function the parameters γ_{ij} can be shown to be related to σ_{ij} and the factor shares as follows:

(i) $\sigma_{ij} = 1 + (\gamma_{ij}/S_iS_j)$ for all i,j i = j

(ii) $\sigma_{ii} = (\gamma_{ii} + S_i^2 - S_i)/S_i^2$ for all i

The above elasticities are not constrained to be constant as in the Cobb-Douglas and the CES functions but depend on factor share and input coefficients.

Elasticities of Factor Demand

The price elasticities of input demand (ED) both respect to own and other prices are also derived from the estimated gamma coefficients. The concepts of AES and ED are closely related. For the translog cost fraction the input demand elasticities are given as follows:

$S_{ij} = S_j \sigma_{ij}$ (cross-price elasticity)

and

$S_{ii} = S_i \sigma_{ii}$ (own price elasticity)

The production structure specified in equation (1) and (2) imposes no a priori restrictions on the elasticities.

Empirical Estimation

The system of equations specified in (1) and (2) was estimated by a non-linear iterative system method using Gauss-Newton Algorithm. The system converged in ten iterations with a criteria of .01. Parameter estimates are presented in table 1. Asymptotic t-statistics reported in the same table imply that most of the coefficients are significant. In particular, coefficients of most interest to us in this study namely γ_{RR}, γ_{QR} and γ_Q are significant at the .05 level.

The parameter estimates presented in Table 1 enable us to calculate both partial and total own price elasticity of demand. The partial own price elasticity of factor demand is given by:

$$\xi_{ii} = \sigma_{ii} S_i = (\gamma_{ii} + S_i^2 - S_i)/S_i^2$$

Table 1: Estimation Results

Parameter	Estimate	t-statistic
α_Q	1.718	12.4
γ_{QQ}	-0.08	-4.5
γ_{QS}	0.015	1.93
γ_{QM}	+0.00714	2.7
γ_{QI}	-0.01415	-1.4
γ_{QR}	-0.00349	-11.2
γ_{QL}	-0.00448	-0.8
α_S	-0.285	-4.2
α_M	-0.135	-5.9
α_I	1.122	13.2
α_R	0.0367	12.5
α_L	0.2618	5.3
γ_{SS}	-0.062	-7.4
γ_{MM}	-0.001	-0.45
γ_{II}	-0.075	-5.3
γ_{RR}	0.00062763	5.1
γ_{LL}	-0.0010206	-3.0
γ_{SM}	-0.002069	-0.5
γ_{SI}	0.065	6.96
γ_{SR}	0.0012	5.1
γ_{SL}	-0.00204	-3.0
γ_{MI}	0.00389	0.6
γ_{MR}	0.00126	5.1
γ_{ML}	-0.00204	-3.0
γ_{IR}	-0.001097	-1.96
γ_{IL}	0.00714	3.0
γ_{RL}	-0.00204	-3.0
ϕ_t	0.0330	2.7
ϕ_{tt}	-0.0014	-3.4
ϕ_{tS}	0.00647	2.5
ϕ_{tM}	0.000602	0.2
ϕ_{tI}	0.0121	4.3
ϕ_{tR}	0.000108	0.24
ϕ_{tL}	0.019	-8.97
ϕ_{tQ}	-0.00645	-0.438
α_O	-3.6	-6.6

log of Likelihood Function = 3410.9

For R&D capital, partial own price elasticity of demand can be written as: $\xi^{c}_{RR} = S_R\sigma_{RR} = (\gamma_{RR} + S_R^2 - S_R)/S_R^2$

By substituting numerical values for the parameter,

$\xi^{c}_{RR} = -0.8034$

The total own price elasticity of R&D capital, on the other hand, is given by:

$$\xi_{RR} = \xi^{c}_{RR} + \frac{\partial X_R}{\partial Q} \cdot \frac{P_Q}{X_R} \cdot S_R = \xi^{c}_{RR} + N_{RQ} \cdot S_R = -0.1615$$

To obtain the impact of changes in tax credits on additional R&D expenditures, we also need to develop an estimate of the elasticity of the user cost of R&D capital with respect to the credit rate. This can be obtained from the expression for the user cost of R&D capital given in Appendix A (data appendix) as follows:

$$\frac{\partial W_R}{\partial V} \cdot \frac{V}{W_R} = -P_R\ (\rho + \delta_v)\ (1-u_c)\ \frac{V}{W_R} = \phi\ (\text{say})$$

By substituting parameter values and the sample mean values in the above expression we obtain $\phi = -0.49248$

Now additional R&D expenditures can be obtained by multiplying the R&D capital stock by ϕ and ξ_{RR}. Total R&D capital stock for 1983 is estimated to be 10 billion dollars. Thus

Additional R&D Expenditures = 10 X (-0.16150 9-0.49248)

= 0.7959 billion

= $795 million

The total cost of R&D tax credits ($194 million) and R&D allowances ($247 million) in 1983 was $441 million. Thus additional R&D expenditures per dollar cost would be $1.80 (795/441 = $1.80). This suggests that R&D tax credits had a significant positive impact on R&D investment in Canada and for every dollar of revenue foregone by the national treasury $1.80 worth of additional R&D investment was undertaken. Thus R&D tax credit is a cost-effective instrument for the promotion of R&D in Canada.

5. SUMMARY AND CONCLUSIONS

This concluding section brings together conclusions of earlier sections in summary form. In the following, main themes emerging from an analysis of R&D and production structure, R&D and product market structure, rationale for public intervention for R&D investment and the effectiveness of tax policies for R&D investment are presented.

R&D Capital and the Structure of Production

R&D capital, as an input, includes scientific and engineering personnel, laboratories and equipment and related inputs. R&D capital serves as an input in a joint production of multiple outputs which include product and process development. R&D capital facilitates the mapping of technological possibilities into economic opportunities.

R&D takes time to accumulate and uses up scarce resources. It may take several years for a project to proceed from proposal to development stage. R&D capital accumulation serves to create new knowledge relating to new production techniques. Thus it ensures that the process of technical change is evolutionary and cumulative in character. Technological change widens production opportunities for the economy by enabling it to obtain greater outputs with given inputs or the substitution of relatively cheaper inputs for relatively more expensive ones.

A special feature of R&D capital is the imperfect appropriability of returns as a result of intra- as well as inter-industry capital spillovers. Spillovers diffuse knowledge by channels such as patents, cross-licensing agreements, R&D personnel mobility and input purchases. The overall impact of R&D capital spillovers on the incentives to undertake additional R&D investment is unclear in view of two opposing influences. First, the imperfect appropriability of returns from own R&D has a disincentive effect. Second, the desire to tap into the external knowledge and associated benefits promotes incentives to undertake own R&D to develop an internal capability to benefit from externally generated knowledge. The net impact of the above varies by industry and explains the paradox posed by some R&D intensive industries such as electronics and chemicals where the high levels of spillovers do not seem to have any detrimental effects on the incentives to undertake additional R&D investment.

The following broad conclusions emerge from a survey of the available empirical evidence relating R&D capital and the structure of production.

- The overall adjustment process from R&D project initiation to product and process development takes three to five years.
- The marginal adjustment costs for R&D are higher than those for plant and equipment.
- The own price elasticity of demand for R&D capital is less than unity regardless of the time period considered.
- R&D capital is a complement to physical capital but a substitute for labor in the long run.
- The long run output elasticity of demand for R&D capital is close to unity. Short run elasticities are much smaller than those for the long run.
- U.S. subsidiaries in Canada and Canadian-controlled private corporations show similar response in the long run but the short run impact of output changes on R&D capital is more pronounced for the latter.
- Output changes exert a much stronger influence on R&D capital than vice versa.
- The contribution of R&D capital to the productivity growth is inconclusive but more recent work confirms U.S. findings of a positive and significant relationship.
- R&D capital spillovers are large and significant and as a result the social rate of returns on R&D projects exceeds the private returns by at least two-thirds of the private return in Canada.

R&D Capital and Product Market Structure

The value of cost reducing R&D is determined by its profitability. Since private returns from R&D understate true social returns from such investments, R&D will be underprovided. Furthermore, since R&D investments often represent large fixed costs, market structure in R&D intensive industries is going to be concentrated. The above situation is, however, not unique to R&D. What is unique about the R&D is the nature of spillovers. These spillovers reduce industry costs but since they result in inappropriability of returns for the R&D performer, incentives to do R&D are reduced. Restoring appropriability does not help matters either because it results in industrial concentration, incorrect pricing of R&D and resulting social costs. Perfect appropriability may also result in excessive R&D because too many firms may be fishing for the same information.[20]

The information asymmetry between a R&D performer and a financier distinguishes R&D investment from traditional risky investment. It is in the interest of the R&D performer to keep vital project information secret but in the absence of detailed information, project financing may not be forthcoming. Asymmetric information also limits the R&D firm's ability to profit from its output.

The following broad conclusions emerge from a survey of empirical evidence on the relationship between R&D capital and market structure.

- Success breeds success. Since learning involves costs, successful firms possess an advantage over their rivals in enjoying greater possibilities for further success. Thus monopoly persists in the R&D capital market. Past successes of R&D investments lead to greater current R&D efforts on the part of the successful firms. These firms, thereby, tend to produce further innovations and thus widen the gap between themselves and their rivals.
- The relationship between R&D and firm size is much looser and obscure than is implied by the usual statements of Schumpeterian hypothesis. While much of the R&D capital is concentrated in large firms, it is more likely that they have become large because of their

R&D successes. rather than that they do more and more fruitful R&D because they are large.

- R&D capital and industrial concentration are positively correlated up to moderate levels of industrial concentration.
- Intra-industry spillovers drive a wedge between the social and the private return in an industry as well as between the social rates across industries. Social rates of return diverge from the private rates by 50 to 150 percent depending upon the R&D intensiveness of the industry.
- In the presence of spillovers, the society's demand for R&D capital at the existing market rates of return significantly exceeds the private demand.

Public Policy and R&D Investment

It has been argued that social rate of return from R&D is higher than the private rate of return due either to the presence of spillovers or information asymmetries. Due to the presence of spillover, the R&D performer is not able to fully appropriate benefits associated with his activity. The presence of asymmetric information between R&D performer and financier limits financing of R&D projects. Project success warrants secrecy but project financing requires release of vital information. As a result many projects lapse, lacking financing. The asymmetric information in the R&D output market also limits the R&D firm's ability to achieve licensing gains from trade.

Most industrial nations see the need to intervene through the tax code to encourage R&D activities. Empirical evidence on the effectiveness of such initiatives is quite limited. This study examined the impact of Canadian R&D tax credit on R&D investment using a production structure framework. This framework enables a researcher to trace the impact of tax policies on production and investment decisions of an industry. An implementation of this framework was carried out by using detailed data on inputs and outputs and factor and output prices and tax regime for 18 Canadian industries for the period 1963 to 1983. Provisions in the tax code were used to develop estimates for the user cost of capital. A system of simultaneous equations incorporating the cost function and derived input demand functions was estimated using non-linear interactive methods in translog form. The estimated cost function fitted the data well and also was "well-behaved". An analysis of parameter estimates for this cost function suggests that R&D tax credit had a significant positive impact on R&D investment in Canada and for every dollar of revenue foregone by the national treasury $1.80 worth of additional R&D investment was undertaken. This suggests that a properly designed tax incentive can further public policy objectives in a cost-effective manner.

NOTES

1. Conventionally defined, knowledge capital or R&D capital inputs primarily refer to an aggregation of scientists, engineers, other R&D personnel, laboratories and associated equipment and related expenditures into a single or a few broad categories. See Bernstein (1986), Bernstein and Nadiri (1984), Griliches (1979) and Mansfield (1968). Following Mansfield (1968), "research" in this paper refers to original investigations directed to the discovery of new scientific knowledge, and "development" entails all technical activities geared to translating research findings into products and processes. Mansfield (1968) also argued that the amount of R&D capital in a particular industry depends upon the resources devoted by firms, independent investors and governments to the improvement of the industry's technology.

2. See Bernstein (1986c), pp. 2-5.

3. Mohnen et. al. (1986) found that the rates of return (net of depreciation and adjustment costs) for R&D capital were higher than those for the physical capital and that these rates were higher for Japanese industries than those for U.S. and West Germany. One structural explanation concerns the financing of R&D. In 1975, only 1.7 percent of gross expenditures on R&D performed by the manufacturing sector were funded by government in Japan compared to 13.5 percent in Germany and 35.4 percent in the U.S. The authors contend that the absence of adequate government support may be a motivating factor for Japanese managers to direct their R&D efforts to more profitable projects. See Mohnen et. al. (1986), p. 765.

4. Similar results were found by Lichtenberg and Siegel (1991) for a more recent sample.

5. See Bernstein (1985), pp. 25-26 for further insights in R&D spillover mechanisms.

6. See also Nelson (1982).

7. Nelson (1982) notes that even rival firms make "logy" (theory as opposed to technique which refers to a way of doing something) public although the technique is kept private. This practice serves to reduce the deadweight loss associated with keeping R&D efforts completely secret.

8. First version August 1986; final version accepted November 1988.

9. First version 1987; final version accepted May 1988.

10. Value in 1987 dollars.

11. See Nelson and Winter (1982), pp. 130-131.

12. See Kamien and Schwartz (1975), pp. 16-18 and also Kamien and Schwartz (1982), pp. 75-84.

13. See Kamien and Schwartz (1975), pp. 8-11 and Dasgupta (1982), p. 8.

14. See Scherer (1967b).

15. See Mansfield (1968a), Scherer (1965b), Freeman (1971), Johannison and Lindstrom (1971) and Schwartzman(1976). Following Mansfield (1968), "research" in this paper refers to original investigations directed to the discovery of new scientific knowledge, and "development" entails all technical activities geared to translating research findings into products.

16. See Levin (1986). A recent example of inventing around is Eastman Kodak's instant cameras. A superior court recently ruled that these infringed on the patent rights of Polaroid Corporation. See Mansfield, Rapoport, Romeo, Wagner and Beardsley for a thorough discussion of this topic and empirical estimates.

17. See also Spence (1984) for a formal treatment of this problem.

18. This section is based on Congressional Budget Office (1985), pp. 19-29 and Kaplan, Ijiri and Visscher (1982).

19. This section draws heavily from Bernstein (1986).

20. See Scherer (1967b).

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Appendix A: *THE DATA*

Most of the data used in this study is drawn from the Economic Council of Canada data bank for the Candide Model and covers the period 1963 to 1983. Three digit level of aggregation is used for a sample of 18 industries. The following industry aggregates are included in our sample.

1. Communications & Transportation
2. Crude Petroleum
3. Mining
4. Utilities
5. Furniture and Fixtures
6. Iron and Steel
7. Non-Ferrous Metals
8. Metal Fabricating
9. Machinery Except Electrical Machinery
10. Non-Auto Transport Equipment
11. Motor Vehicles Except Parts and Accessories
12. Electrical Products
13. Non-Metallic Mining Products
14. Food and Beverages
15. Rubber and Plastics
16. Textiles
17. Petroleum and Coal Products
18. Chemical and Chemical Products

The following series were obtained either from the CANDIDE Model 3.0 data bank or from other sources in the Economic Council of Canada.

Gross output in current dollars:

Gross output in constant (1971) dollars:

Manhours: These series were developed by Rao and the details of construction are given in Ostry and Rao (1980, pp.59-62).

Wages:

Capital Stock - Structures:

User Cost of Structures: Estimates are from Lodh (1984) using a modified Hall-Jorgenson (1967) approach to take into account sector specific depreciation rates, tax parameters, and debt equity ratios.

Capital Stock - Machinery and Equipment:

User Cost of Machinery and Equipment: Estimates are from Lodh (1984).

Intermediate inputs in current dollars:

Intermediate inputs in constant (1971) dollars:

Energy consumption in current dollars:

Energy Price Indices: The data are from Rao and Preston (1983).

In addition, the data was also collected or estimated for the following series:

R&D Price Indexes: Precious studies on the subject have invariably used the GNE implicit deflator, the GNE implicit price index for machinery and equipment or the Consumer Price Index to deflate R&D expenditures. The GNE deflator or the CPI are inappropriate deflators for the R&D expenditures because they relate to output measures of economic activity whereas R&D serves as an input in the production process. The GNE implicit price index is also inappropriate as a deflator because more than 80 percent of R&D expenditures represent operating as opposed to capital expenditures. Fortunately, Bernstein (1986b) has developed price indexes for Canadian Industrial R&D expenditures. These series were used in this study.

R&D Tax Credits, R&D Allowances and R&D Expenditures: These series were compiled from various releases of the Statistics Canada and from unpublished data files of Statistics Canada.

R&D Capital Stock: These data series were constructed using a perpetual inventory method (see Mohnen et al. 1986). The benchmark data is obtained from the first period R&D expenditure as follows:

Period 1:

R&D Expenditure (1)/Price Index (1) = R&D Investment (1)

R&D Capital (1) = Public Investment (1)/(n + δ)

where n = rate of growth of real output

δ = depreciation rate

Period 2:

R&D Capital Stock (2) = R&D Expenditure (2)/R&D Price Index (2)

+ (1 - δ) R&D Capital (1)

and so on.

User Cost of R&D Capital: It was estimated using the following formula (see Bernstein 1986c):

where P = acquisition price of R&D capital

p = discount rate

d_2 = depreciation rate

u_c = Income tax rate

= effective credit rate

d_r = present value of incremental allowances for R&D expenditures.

Total Cost: The total cost of output was estimated by applying input prices (user costs) to input quantities. For this purpose, five inputs are considered, namely, structure capital, machinery capital, R&D capital, intermediate inputs and labor.

Appendix B: ***Financial Assistance for Research and Development in Canada***

The following federal programs are currently available in Canada for the support of R&D activities:

1. Industrial and Regional Development Program (IRDP). This program provides grant and/or loan support to a wide variety of projects. 1984/85 cost of the program was $110.2 million.
2. Industrial Research Assistance Program (IRAP). This program provides support for applied industrial research. 1984/85 cost was $48 million.
3. Defense Industry Productivity Program (DIPP). Matching grants/loans are available to defense contractors and subcontractors through this program. 1984/85 cost was $131 million.
4. Program for Industry/Laboratory Projects (PILP). This program provides financing for industrial applications of R&D output of public agencies. 1984/85 cost was $29 million.
5. Scientific and Technical Information. Canada Institute for Scientific and Technical Information and National Research Council provide such information to business at minimal or no cost.
6. Training Assistance. Funding for training is provided through three major programs; Skills Growth Fund, National Institutional Training Program and the National Industrial Training Program (NITP). 1984/85 cost was $294 million.
7. Technology Support Through Procurement. 1984/85 cost of this program was $26 million.
8. Technology Support Through Institutes: About $5 million in annual support for industrial research centers is provided through this program.
9. Departmental Programs: Several federal departments have programs designed to assist technology development in specific industries or areas. 1984/85 cost was $72 million.

10. Patents Support

11. Public Awareness of Science and Technology: 1984/85 cost was $1.5 million.

12. Support for University/Industry Cooperative Programs: 1983/84 cost of this program was $36 million.

Under a new program announced in July 1986, the federal government undertook to match dollar for dollar the private sector contributions to University research.

Appendix C: ***Definition of Scientific Research and Experimental Development***

Regulation 2900 of the Income Tax Act (section 37) defined "scientific research and experimental development" (SRED) as a "systematic investigation or search carried out in a field of science or technology by means of experiment or analysis". The technology was defined as a systematic study of the application of scientific knowledge to industrial processes or product development.

"(a) basic research, namely work undertaken for the advancement of scientific knowledge without a specific practical application in view,

(b) applied research, namely work undertaken for the advancement of scientific knowledge with a specific practical application in view, or

(c) development, namely use of the results of basic or applied research for the purpose of creating new, or improving existing materials, devices, products or processes."

Activities in engineering or design, operations research, mathematical analysis or computer programming and psychological research are eligible only if such activities are undertaken directly in support of basic or applied research or eligible development activities.

The following activities are excluded from SRED.

- market research and sales promotion;
- quality control or routine testing of materials, devices or products;
- research in the social sciences or the humanities;
- prospecting, exploring or drilling for or producing minerals, petroleum or natural gas;
- the commercial production of a new or improved material, device or product or the commercial use of a new or improved process;
- style changes;
- routine data collection.

Revenue Canada circular 86-4 provides a detailed interpretation of section 37 and regulation 2900 of the Income Tax Act relating to tax provisions for scientific research and development.

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